Corneal and total wavefront aberrations in phakic and pseudophakic eyes after implantation of monofocal foldable intraocular lenses

Hans Peter Iseli, MD, Mirko Jankov, MD, PhD, Michael Bueeler, PhD, Yves Wimmersberger, MD, Theo Seiler, MD, PhD, Michael Mrochen, PhD

PURPOSE: To compare the correlation between corneal and total wavefront aberrations in normal phakic and pseudophakic eyes after implantation of foldable monofocal intraocular lenses (IOLs).

SETTING: University Hospital, Eye Clinic, Zurich, Switzerland.

METHODS: Wavefront aberrations and corneal topography of 29 eyes that had cataract surgery with implantation of hydrophobic monofocal foldable IOL (AcrySof, Alcon Labs) were measured at least 2 months postoperatively and compared with wavefront measurements performed in 33 normal young phakic eyes. The total wavefront aberrations were measured by means of a Tscherning wavefront sensor at a wavelength of 660 nm (Allegro Wave Analyzer, WaveLight Laser Technology). The corneal aberrations were derived from corneal topography measurements ascertained with a Placido-based topography system (Keratograph 70600, Oculus). The correlations between corneal and total wavefront aberrations were calculated for all Zernike coefficients from 2nd up to 6th order.

RESULTS: There was a significant correlation between corneal and total wavefront aberrations in astigmatism C3 and C5 as well as for all 3rd-order Zernike coefficient in both groups (except C8 in the pseudophakic group). The correlation between corneal and total astigmatism (C3 and C5) was higher in the pseudophakic than in the phakic eyes. In contrast, the correlation for the coma-like aberrations was weaker in the pseudophakic eyes ($R>0.18$) than in the group of phakic eyes ($R>0.58$). In both groups, there was no significant correlation between spherical aberration C12 of the cornea and the C12 of the total eye.

CONCLUSION: After cataract surgery with an IOL implantation, both vertical and horizontal coma, as well as spherical aberration, were of higher value than in normal eyes. The compensation effect for corneal aberrations of the natural lens is absent in the IOL and explains these findings. The corneal aberrations in pseudophakic eyes reflect better the optical quality of the total eye than the phakic eyes. Nevertheless, the missing correlation in some specific aberrations, such as C8 and C10, shows the inability of corneal topography to provide suitable information on the optical quality of the total eye after cataract surgery. Thus, both corneal and total wavefront measurements are relevant for the assessment of outcomes after cataract surgery.

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After successful cataract surgery with correct intraocular lens (IOL) implantation and adequate refractive outcome, patients often complain about visual side effects (ghost images, glare, halos) and reduced visual acuity of a late onset.[1,2] Causes of these symptoms can be capsule opacification and more optical errors of the visual pathway, also called aberrations of higher orders. The principles of development and treatment of capsule opacity are well known.[3] Nevertheless, most pseudophakic eyes suffer from visual disturbance, even when such opacities are removed successfully. One reason might be the higher-order optical aberrations that are present or higher in the pseudophakic eyes than in normal eyes with a natural crystalline lens in loco.[4,5]

Corneal topography and wavefront aberrometry are commonly accepted methods to measure aberrations of the cornea and of the entire eye.[5–18] Although wavefront

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measurements are not capable of measuring edge glare or diffraction, they allow measurement of higher-order aberrations (HOAs) and explanation of some of the visual disturbances.

In this report, the aberrations of intraocular patterns are studied. The difference in aberrations of the entire eye and the corneal aberrations results in calculated aberrations of the internal optics (posterior corneal surface, lens, and vitreous). Presuming that there is minimal or no change in wavefront through posterior corneal surface[8,15] and vitreous (preoperative and postoperative), it could be assumed that the difference in aberrations is caused by to the exchange of the natural crystalline lens by an artificial IOL with different optical properties. Patients with keratoconus, pellucidal degeneration, or other corneal dystrophies were excluded because of the higher influence of posterior corneal surface on aberrations.

The objective of this work was to measure and compare HOAs between corneal and total wavefront aberrations in normal phakic and pseudophakic eyes after implantation of foldable monofocal IOLs.

PATIENTS AND METHODS

Two groups of patients were investigated at the University Hospital of Zurich regarding the monochromatic aberration. The demographic and clinical data in both groups are shown in Tables 1 and 2.

Twenty-nine eyes of 28 patients in the first (pseudophakic) group had uneventful cataract surgery with IOL implantation at least 2 months before investigation. Patients were selected for cataract surgery on the basis of clinically evident lens opacification with no coexisting ocular pathology. A standard postoperative ophthalmic assessment was performed in all patients and included visual acuity, manifest refraction, anterior segment slitlamp biomicroscopy, dilated pupil fundus examination, intraocular pressure measurement, keratometry, and ultrasound biometry. Exclusion criteria were (1) use of contact lens, (2) history of perforating keratoplasty, (3) refractive cylinder of more than 3.5 diopters (D), (4) age greater than 85, (5) corneal diseases, and (6) best spectacle-corrected visual acuity worse than 20/80 with pinhole.

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From the Institute of Refractive and Ophthalmic Surgery (Iseli, Bueeler, Seiler, Mrochen), Zurich, Switzerland, the Vardinoyiannion Eye Institute of Crete (Jankov), University of Crete, Greece, the Swiss Federal Institute of Technology (Bueeler, Mrochen), Zurich, Switzerland, and the University of Zurich (Wimmersberger), Department of Ophthalmology, Zurich, Switzerland.

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Reprint requests to Michael Mrochen, PhD, IROC, AG, Institute for Refractive and Ophthalmic Surgery, Zurich, Stockerstrasse 37, CH-8002 Zurich, Switzerland. E-mail: info@iroc.ch.

Table 1. Demographic and clinical data of pseudophakic patients.

Parameter	Result
Age (y)	
Mean ± SD	67 ± 11
Range	41 to 81
Sex (M/F)	14/14
Eye (R/L)	14/15
Mean refraction (D) ± SD	
Sphere	−0.48 ± 0.95
Cylinder	−1.06 ± 0.57

Table 2. Demographic and clinical data of phakic patients.

Parameter	Result
Age (y)	
Mean ± SD	39 ± 9
Range	22 to 58
Sex (M/F)	15/7
Eye (R/L)	16/17
Mean refraction (D) ± SD	
Sphere	−4.41 ± 2.76
Cylinder	−0.84 ± 0.71

All selected eyes had the same procedure in 2001 by the same surgeon: Corneoscleral tunnel 3.75 mm, phacoemulsification, and insertion of a monofocal IOL (AcrySof, Alcon Labs) lens in the bag, because it is believed that a scleral tunnel incision is the best way to minimize corneal topographic change after cataract surgery.[11–13]

Group 2 (normal eyes) had 22 patients with 33 phakic myopic eyes preoperative to Exclusion criteria in this group were (1) less than 18 years old, (2) history of eye disease, (3) best corrected visual acuity worse than 20/20, and (4) manifest refractive cylinder of more than 3.0 D.

Corneal topography was performed by a Placido-ring based corneal videotopography system (Keratograph 70600, Oculus) at least 3 minutes after the instillation of artificial tears (Hylocomod) to prevent tear-film breakup during the measurement procedure but still not interfere significantly with the measurement results. Twenty minutes after 2 drops of tropicamide 1% (Mydriaticum Dispersa) were administered and the pupils were at least 7 mm in diameter, wavefront aberrometry (Allegro Wave Analyzer, WaveLight Laser Technology) was carried out producing 5 good-quality maps. All the measurements for aberrometry and corneal topography were centered on the line of sight and the data exported with the reference to the pupil center.

Total wavefront aberrations as well as the corneal aberrations (W) were expressed by Zernike expansion:

$$W(x,y) = \sum_{i=0}^{27} CiZi(x,y)R$$

where C_i = Zernike coefficients, Z_i = Zernike polynomials, and R = analyzed pupil radius. A detailed description of the Zernike representation for corneal topography and wavefront was given by Mrochen et al.[15]

Zernike coefficients were calculated for a pupil diameter of 6.0 mm. Corneal aberrations from corneal topography (limited to the central 6.0 mm) were correlated with the total wavefront aberrations by means of a linear regression (Spearman rank correlation coefficient). A commercially available software package (Origin 6.0, Mircocal Inc) was used for data analysis.

Plotting the total wavefront over the corneal wavefront aberrations and applying linear regression of each Zernike coefficient results in 1 of the following possibilities:

1. There is a significant correlation ($P < .05$) between corneal and total wavefront. In this case, the slope can be (a) equal to 1 (m = 1), implicating that the total aberration is caused by corneal aberration; (b) if $m < 1$, the corneal wavefront is partially compensated by other structures within the eye; (c) if the total optic aberration is greater than corneal aberration, $m > 1$.
2. No significant correlation is found if the corneal aberration is totally compensated or if wavefront aberrations are caused by internal eye structures.

Subtraction of corneal aberration from wavefront aberration is permitted only if the condition that they relate to the same plane of reference is fulfilled. The wavelight topolyzer system was used, which measures along the vertex normal; however, all required data to reconstruct centration on the line of sight are provided. Thus, the topography data were recalculated with respect to the line of sight, even knowing that this might be coupled with small errors regarding the reference axis. Numerical overlapping methods were used to increase the highest possible matching. Both systems must be able to determine the pupil center, which they do.

In both groups, phakic and pseudophakic, tilt (C1, C2), and defocus (C4) were not considered. Linear regression was calculated for C3 to C27. Third-order comalike aberrations C7 and C8 as well as 4th-order spherical aberration C12 were analyzed in more detail because they were pointed out to be the most important HOAs.[19]

RESULTS

Phakic Eyes

Data of linear regression analysis of corneal and total wavefront aberration C3 through C27 in phakic eyes are listed in Table 3.

Correlation Coefficient and Statistical Significance

Considering the significance of the correlation between corneal and total eye aberration (Table 3), it was found that all 3rd-order aberrations were statistically significant. From 4th order to 6th order, only C18 presents a *P* value of less then .05. All mentioned aberrations have a moderate or strong linear correlation (*R*).

Slope (m) of Linear Function

In all above-listed significant correlations, the slopes were positive and ranged from 0.09 (C18) to 0.68 (C3).

Table 3. Linear regression analysis data of corneal and total aberration of C3 to C27 in normal phakic eyes.

Zernike Coefficient	Polynoms	*m*	*R*	*P*
C3	Astigmatism (2nd order)	0.68	0.71	<.00001*
C5	Astigmatism (2nd order)	0.58	0.75	<.0001*
C6	3-foil (3rd order)	0.14	0.35	.026*
C7	Coma (3rd order)	0.28	0.58	<.0001*
C8	Coma (3rd order)	0.33	0.66	<.0001*
C9	3-foil (3rd order)	0.24	0.43	.006*
C10	4-foil (4th order)	0.06	0.18	.28
C11	Astigmatism (4th order)	0.06	0.16	.32
C12	Spherical aberration (4th order)	0.1	0.29	.07
C13	Astigmatism (4th order)	0.01	0,07	.69
C14	4-foil (4th order)	0.08	0.27	.09
C15	5-foil (5th order)	0.06	0.24	.14
C16	3-foil (5th order)	0.03	0.19	.23
C17	Coma (5th order)	0.24	0.15	.35
C18	Coma (5th order)	0.09	0.46	.003*
C19	3-foil (5th order)	0.06	0.26	.11
C20	5-foil (5th order)	−0.03	−0.25	.12
C21	6-foil (6th order)	0.03	0.18	.28
C22	4-foil (6th order)	0.06	0.06	.3
C23	Astigmatism (6th order)	0.01	0.04	.82
C24	Spherical aberration (6th order)	0.02	0.09	.6
C25	Astigmatism (6th order)	0.01	0.03	.25
C26	4-foil (6th order)	−0.03	−0.18	.27
C27	6-foil (6th order)	−0.01	−0.07	.66

*Statistically significant, $P < .05$

This means that, in general, corneal aberrations exceeded the corresponding values for total wavefront aberration.

Pseudophakic Eyes

Data of linear regression analysis of corneal and total wavefront aberration C3 through C27 in pseudophakic eyes are listed in Table 4.

Correlation Coefficient and Statistical Significance

Considering the significance of correlation between corneal and total eye aberration (Table 4), it was found that all 2nd-order and 3rd-order aberrations (except C8) were statistically significant. From 4th order to 6th order, C11, C14, C15, C16, C18, C20, and C24 presented a *P* value less then 0.05.

Slope (m) of Linear Function

In all above-listed significant correlations, only the 4th-order astigmatism (C11) featured a negative slope ($m = -0.76$). All others showed a positive slope with a range from 0.39 (C9) to 1.27 (C18).

Also in the pseudophakic group, corneal aberrations exceeded the corresponding values for the total wavefront aberration (except C11). But here in all cases, slope *m*, for all mentioned aberrations, was steeper than in the phakic group (except C8).

Comparison of Both Groups

Figure 1 shows the linear regression of C3 and C5, C7 and C8, and C12. Except C8, the gradients of all slopes were steeper in pseudophakic than in phakic eyes.

In Figure 2 the difference in Zernike coefficients between the corneal and total wavefront aberrations for the phakic group (Figure 2, *top*) and pseudophakic group (Figure 2, *bottom*) for all eyes are noted. Statistical differences for the mean difference in corneal and total wavefront were tested by means of a Student *t* test for different variances. Significant differences ($P<.05$) were found only for 3-foil C9, 4th-order spherical aberration C12 and 6th-order spherical aberration C24. The difference between corneal and total 4th-order spherical aberration in phakic and pseudophakic eyes was found to have opposite signs, indicating that spherical aberration of intraocular structures in pseudophakic eyes are not equal to the natural spherical aberration of intraocular structures in the phakic group. The F test for different variances was significant for all Zernike coefficients from the 2nd to the 6th order, except for horizontal coma C8, 3-foil C9, and 4th-order astigmatism C11.

Table 4. Linear regression analysis data of corneal and total aberration of C3 to C27 in pseudophakic eyes.

Zernike Coefficient	Polynoms	*m*	*R*	*P*
C3	Astigmatism (2nd order)	0.89	0.84	<.0001*
C5	Astigmatism (2nd order)	0.81	0.94	<.0001*
C6	3-foil (3rd order)	0.46	0.68	<.0001*
C7	Coma (3rd order)	0.59	0.44	.0043*
C8	Coma (3rd order)	0.16	0.13	.48
C9	3-foil (3rd order)	0.39	0.48	.009*
C10	4-foil (4th order)	0.08	0.044	.82
C11	Astigmatism (4th order)	0.28	−0,42	.029*
C12	Spherical aberration (4th order)	0.28	0.31	.095
C13	Astigmatism (4th order)	0.078	6.70E-02	.73
C14	4-foil (4th order)	0.62	0.55	.002*
C15	5-foil (5th order)	0.64	0.4	.033*
C16	3-foil (5th order)	0.77	0.43	.02*
C17	Coma (5th order)	0.65	0.33	.08
C18	Coma (5th order)	1.27	0.56	.002*
C19	3-foil (5th order)	0.07	0.05	.78
C20	5-foil (5th order)	0.63	0.42	.024*
C21	6-foil (6th order)	0.42	0.14	.47
C22	4-foil (6th order)	0.29	0.2	.29
C23	Astigmatism (6th order)	0.27	0.29	.12
C24	Spherical aberration (6th order)	0.72	0.43	.017*
C25	Astigmatism (6th order)	0.53	0.34	.07
C26	4-foil (6th order)	0.28	0.21	.277
C27	6-foil (6th order)	1.58	0.24	.21

*Statistically significant $P<.05$

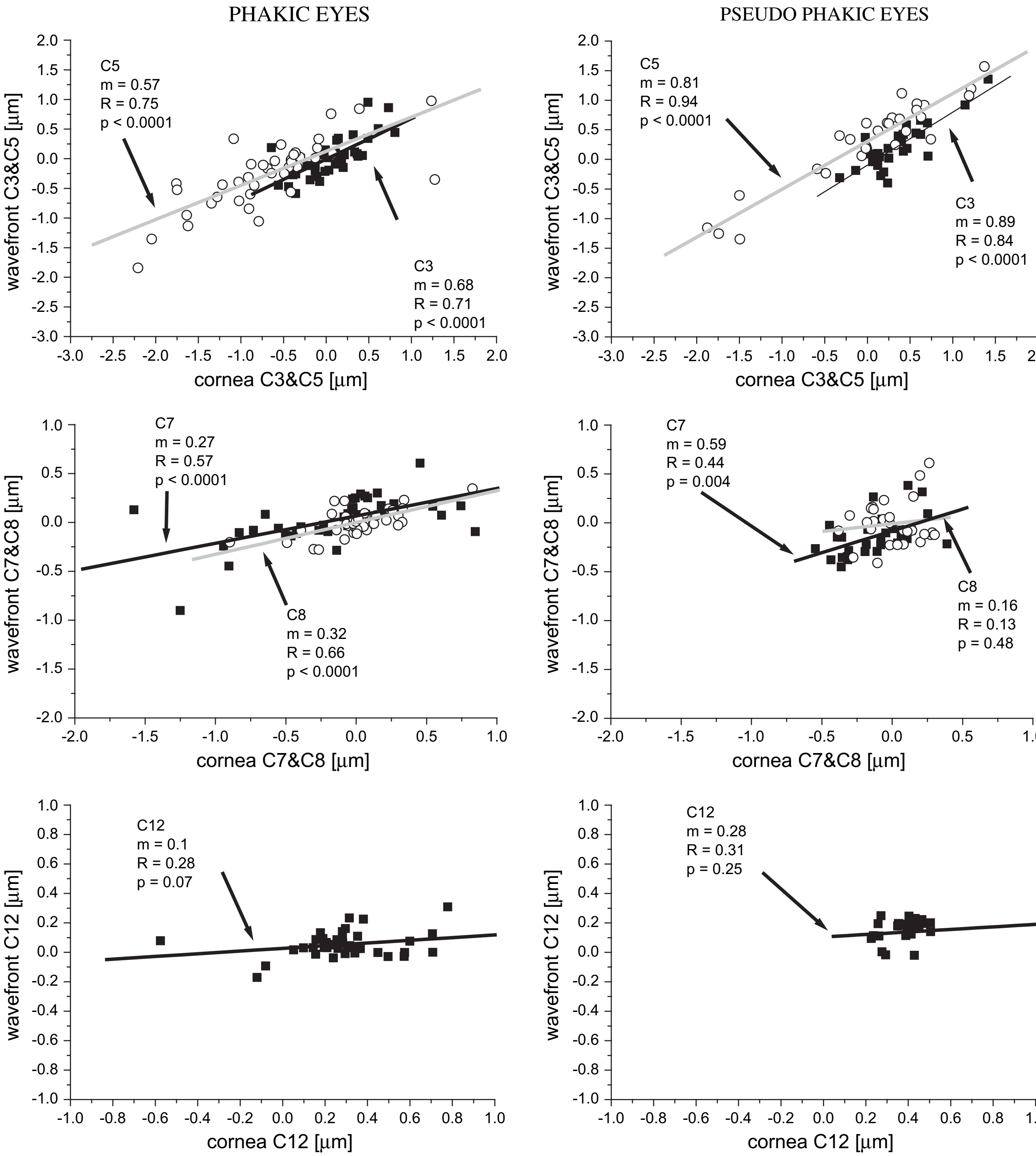

Figure 1. Comparison of the correlation between corneal and total aberration in normal phakic eyes (*left*) and pseudophakic eyes (*right*) for astigmatism (*top*), 3rd-order coma (*middle*), and 4th-order spherical aberration (*bottom*). R = correlation coefficient; p = statistical significance of the correlation; m = slope factor of linear fit. Zernike coefficients were calculated for a 6.0 mm pupil.

DISCUSSION

Cataract extraction with refractive IOL implantation surgery is one of the most frequently performed procedures in older people to improve the optical quality. Today, cataract surgery can successfully reduce aberrations of lower order (sphere and cylinder) but is not intended to reduce

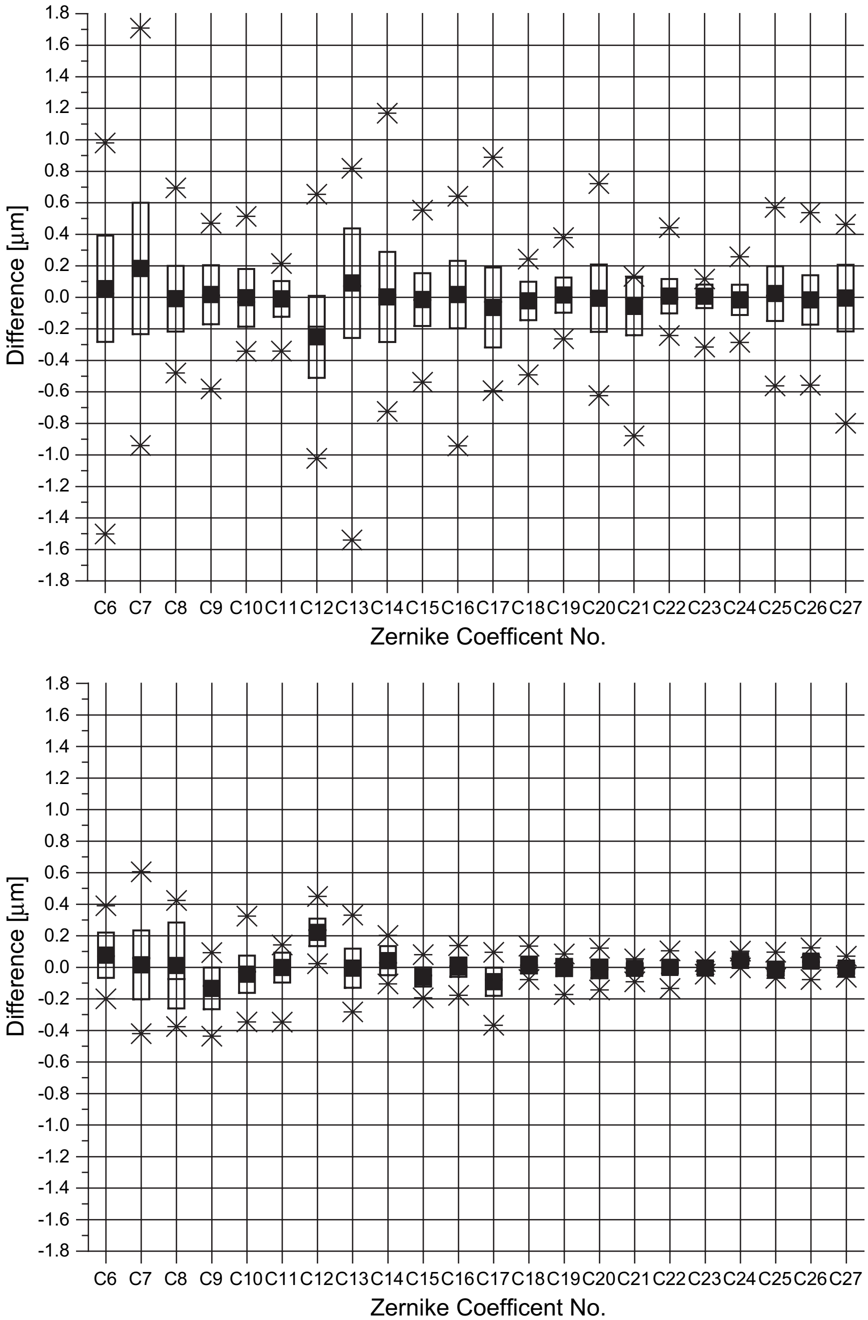

Figure 2. Difference between corneal and total wavefront aberrations in 3rd-order to 6th-order Zernike coefficients in the phakic (*top*) and the pseudophakic eyes (*bottom*). The mean values are represented by the squares, the standard deviation is shown as boxes, and the 99% and 1% percentiles are shown by the crosses. Significant differences between the mean values were found for 3-foil C9, 4th-order spherical aberration C12, and 6th-order spherical aberration C24. The variance for all coefficients was significantly larger in the pseudophakic group (*bottom*) than in the phakic group (*top*), except for horizontal coma C8, 3-foil C9, and 4th-order astigmatism C11. Zernike coefficients were calculated for a 6.0 mm pupil.

aberrations of higher order. The optical quality of eye is neither sufficiently described by sphere and astigmatism nor by the corneal topography.

Optical aberrations of the cornea are known to be balanced by the intraocular structures of the human eye.[6–10,15–17] A degradation of this natural balance by any refractive surgery procedure (including crystalline lens exchange) leads to a significant reduction in retinal image quality and might therefore account for visual symptoms or reduces contrast sensitivity observed after surgery.[1,2,20–24] Our results support this theory as shown by the simulations in Figure 3. Here, the retinal image quality was derived from the corneal and total wavefront aberrations in the phakic and pseudophakic groups. In both groups, the corneal aberrations have a worse retinal image quality than the total wavefront aberrations. However, the image qualities resulting from total aberrations in the phakic eyes are significantly better than the retinal image

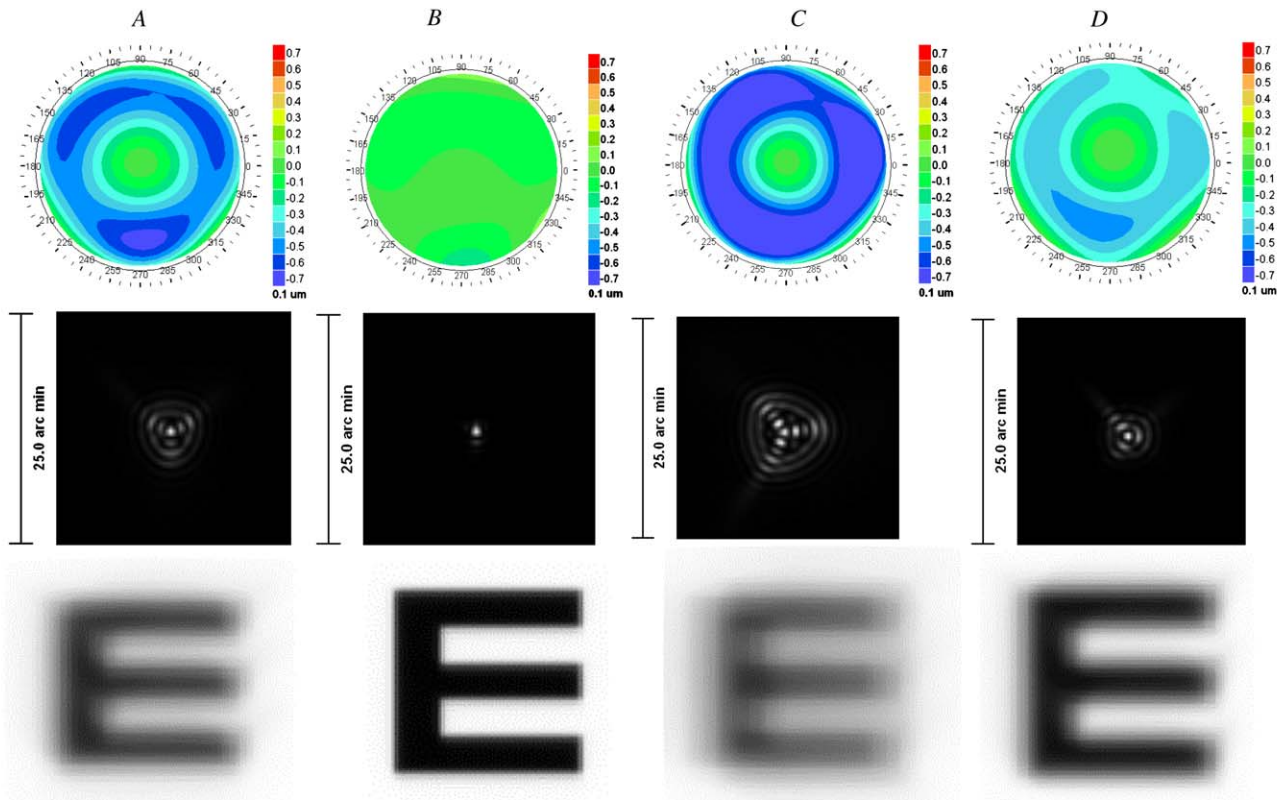

Figure 3. Simulation of the retinal image quality based on the mean wavefront aberrations of the cornea and total wavefront aberrations. *A*: Corneal wavefront aberrations in the phakic eyes. *B*: Total wavefront aberrations in the phakic eyes. *C*: Corneal wavefront aberrations in the pseudophakic eyes. *D*: Total wavefront aberrations in the pseudophakic eyes. Simulations were performed with VisualOpticsLab (version 6.46; Saver and Associates Inc). Simulations were performed for a 6.0 mm pupil.

quality in the pseudophakic eyes. This is probably a result of a significantly larger number of monochromatic aberrations observed in the pseudophakic eyes than in the phakic eyes.

Artal et al.[7] explained that the posterior corneal surface contributes only a small portion to the total aberration of the eye compared with the anterior corneal surface and the crystalline lens. Therefore, the Zernike coefficients in a pseudophakic eye should have almost the same values for corneal and total aberration with an R of almost 1 and should show a slope of $m = 1$ if intraocular aberration is of minor influence.

Measurement Technique

Although both centering on the line of sight, wavefront and corneal aberrations were measured with 2 different devices, resulting in centration errors even when the pupils were dilated during both measurements. Another source of error is the use of artificial tears during corneal topography and wavefront sensing. Although an earlier study performed at our facility found no significant changes in the corneal aberrations when applying hyaluronic acid in normal healthy eyes, the pseudophakic group in the current study included primarily older patients and, thus, the smoothing effect associated with the use of the artificial tears might have resulted in an unrealistic decrease in the measured HOAs.

Data Analysis

Wavefront sensing usually completely ignores scattering components in the optical pathway of an individual eye. Therefore, one could predict a better optical performance than it really is if only the monochromatic aberrations are measured. McLellan et al.[14] compared double-pass measurements performed by Guirao et al.[25] and found that the modulation transfer function (MTF) derived from Zernike coefficients suggests a better image quality than the MTFs calculated form the double-pass method. This is to be expected, because the double-pass system includes the effect of both scattering and HOAs, whereas the Zernike representation includes only the HOAs. Deriving the MTFs with VisualOpticsLab for corneal and total wavefront aberrations measured in our study resulted in almost equal MTFs for the corneal aberrations in both groups (Figure 4). Conversely, there was a significant difference between the 2 groups in the total wavefront aberrations, where again the phakic eyes showed a better optical performance than the pseudophakic eyes. It is worth mentioning that the MTF for the normal subjects in our study provided a better image quality that the MTFs in young subjects reported by McLellan et al[14] and Guirao et al.[25] However, we found a good agreement with the MTF reported by Calvier and coauthors.[26] The large difference in the representation of MTFs requires further standardization.

The phakic group included 33 eyes of 22 patients, the pseudophakic group 29 eyes of 28 patients. A lack of the present study is the use of partner eyes in different groups can lead to certain bias because there is a high intrapatient correlation between the partner eyes in HOAs.[27] However, the aim of this study was to show in general the loss of the natural balancing between corneal and internal aberration after IOL implantation. This specific group had only 1 partner eye included. Further studies on corneal and total wavefront aberrations should carefully address this topic to avoid a certain bias in their study cohorts.

Paquin et al[28] showed that optical quality decreases as myopia increases. This indicates that our results more likely underestimate the difference between normal phakic and pseudophakic eyes. Other investigators found that myopia is accompanied by moderate or no increase in HOA.[29]

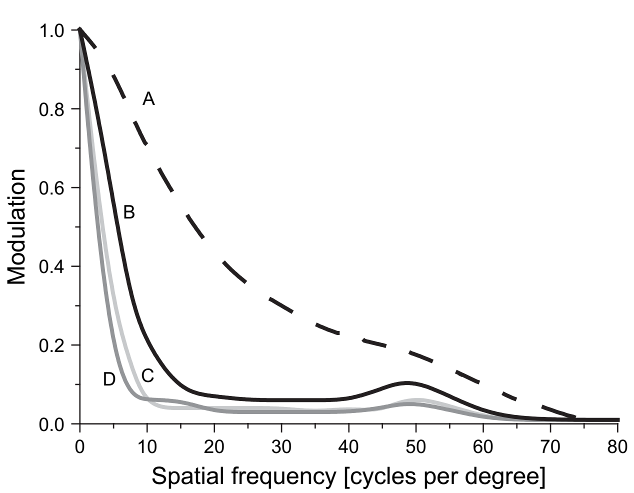

Figure 4. Modulation transfer functions calculated from the mean wavefront aberrations of the cornea and total wavefront aberrations. *A*: Total wavefront aberrations in the phakic eyes. *B*: Total wavefront aberrations in the pseudophakic eyes. *C*: Corneal wavefront aberrations in the phakic eyes. *D*: Corneal wavefront aberrations in the pseudophakic eyes. Simulations were performed with VisualOpticsLab. Modulation transfer functions were calculated for a 6.0 mm pupil.

Comparison of Astigmatism

Phakic Eyes

In phakic eyes, C3 and C5 showed a slope of 0.68 and 0.58, respectively. Corneal astigmatism is generally higher than manifest refractive astigmatism, which fits nicely with the fact that the corneal astigmatism in phakic eyes is compensated by lenticular astigmatism.[7,9] Holladay et al.[30] concluded that most normal eyes possess an intraocular astigmatism of -0.5 D in 90 degrees, whereas the corneal astigmatism was -0.75 D in 0 degrees. Artal et al.[7] showed with 5 phakic patients a compensation mechanism of corneal astigmatism by intraocular structures. Our results in the phakic eyes support these findings, whereas the astigmatism coefficients C3 and C5 derived form the total wavefront are smaller (slope $m < 1$) compared with the astigmatism coefficients calculated from corneal topography (Figure 1).

Pseudophakic Eyes

In the pseudophakic eyes, the astigmatism of the cornea is not compensated by the IOL and, thus, the corneal and total astigmatism were found to be almost equal (slope $m \approx 1$). We assume that small differences found here between corneal and total wavefront aberrations were mainly related to the measurement and analysis techniques and errors.

Comparison of 3rd-Order Aberrations

In the phakic eyes, coma-like aberrations C7 and C8 had a significant correlation (Figure 1); however, their slope was reduced compared with that in pseudophakic eyes. These results are supported by findings of Artal et al[7] who calculated a reduced corneal coma of about 50% by the lens. In contrast, there was no significant correlation for C8 and a much weaker correlation for C7 in the pseudophakic group, suggesting that the horizontal coma C8 observed after IOL implantation mainly originated from the mispositioning of the IOL rather than from any compensation mechanism. The dominating vertical coma C7 can also be seen in the wavefront map in Figure 3. Probably the lens changed its position after surgery, as described by different investigators[31–33]; thus, the correlation between corneal and total aberrations was altered. Bueeler et al.[34] reported that the required accuracy for lateral centration of wavefront corrections in normal subjects should be as precise as 0.2 mm to avoid significant optical aberrations at large pupil sizes.[30] One should also keep in mind that the decentrations of 4th-order spherical aberrations result in 3rd-order coma. Thus, our results indicate a vertical shift of the implanted IOL lens with respect to the pupil center (line of sight).

Comparison of 4th-Order Aberration

In the phakic group, the corneal aberration did not correlate with the aberration of the total wavefront. This indicates that in both groups, the spherical aberration of the cornea was compensated for by the internal structures.

In the pseudophakic group, only C11 (4th-order astigmatism) had a significant correlation with a negative m value.

Fourth-order spherical aberration (C12) is an important indicator of contrast sensitivity. In both groups, there was no statistically significant correlation. However, although the phakic eyes showed the negative mean 4th-order spherical aberration, in the pseudophakic eyes it was positive. Thus, the implanted IOL in our study compensated for the preexisting spherical aberration in the individual cornea; however, it seems to have overcorrected it in most of the eyes.

Comparison of 5th-Order and 6th-Order Aberrations

The phakic group had a significant correlation for 5th-order coma (C18) with an slope of 0.09. In the pseudophakic group, the correlation was also significant with a slope of 1.27. It seems like an amplification of C18 by the IOL. Possibly this is the result of minimal decentration of the artificial lens.

Other 5th-order and 6th-order aberrations showed a significant correlation only in the pseudophakic group. This could also be explained by IOL decentration or tilt. But, in general, 5th-order and 6th-order aberrations have a subordinate influence to visual outcome.

Aberrations and Other Intraocular Types

Mester et al.[23] investigated 2 types of IOLs and found that the lens with a modified anterior surface designed to compensate for positive spherical aberration of the cornea results in improved pseudophakic quality of vision compared with an IOL with biconvex spherical surfaces. In addition, Aoshima et al.[35] reported that unlike IOLs, the human lens shows small aberrations in on-axis and oblique incident rays. They compared an anterior convex and posterior convex IOL and found that the anterior convex IOL produced better images but was disadvantageous for focusing on peripheral areas of the fundus. Packer et al.[22,36] evaluated an IOL with a modified prolate anterior surface regarding functional vision. Their results showed better contrast sensitivity measures for the prolate IOL than for the standard monofocal IOL. Thus, compensation of spherical aberration by improved lens design might also improve the visual outcomes in cataract patients.

Aberrations and Senile Miosis

Artal et al.[7] McLellan et al.[14] and Calver et al.[26] showed that in young patients, corneal aberration outweighs total aberration, but the intraocular optical aberrations can balance the corneal aberrations, whereas in older patients, the situation turns to the converse because this "coupling" does not take place anymore. In the latter group, the total aberrations are up to 3 times more compared with those in young people.[14,27] Two phenomena attenuate the effects of this event development: senile miosis and larger tolerance for defocus in a system with larger ocular aberrations. The same effects are also helpful in pseudophakic patients, and one would estimate an even better visual performance in the pseudophakic than in the phakic eyes, as depicted by the wavefront aberrations, because of the smaller pupils that are common in older subjects.

The aim of cataract surgery should be the reduction of the total wavefront aberrations by means of refractive implants. Aberration data measurement by means of wavefront aberrometry and corneal topography are providing useful information on the optical outcome of such procedures. Our results derived from such aberration data indicate that IOLs with a spherical design implanted during cataract surgery do not achieve the natural compensation mechanism of corneal HOAs by internal structures of the eyes in young subjects. Specifically, the spherical aberration of the cornea is overcorrected, and coma-like aberrations are induced by the refractive IOL. Further optimization or customization of IOLs might improve the optical outcome of cataract surgery.

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