Change in corneal aberrations after cataract surgery with 2 types of aspherical intraocular lenses

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PURPOSE: To study the effect of cataract surgery through 3.2 mm superior incisions on corneal aberrations with 2 types of monofocal intraocular lenses (IOLs) with an aspherical design.

SETTING: Instituto de Optica, Consejo Superior de Investigaciones Científicas, and Fundación Jiménez Díaz, Madrid, Spain.

METHODS: Corneal topography of 43 eyes was obtained before and after small corneal incision cataract surgery. Twenty-two eyes had implantation of a Tecnis Z9000 silicone IOL (Advanced Medical Optics) and 21 had implantation of an AcrySof IQ SN60WF acrylic IOL (Alcon Research Labs) using the recommended injector for each IOL type. The intended incision size (3.2 mm) was similar in the 2 groups. Corneal aberrations were estimated using custom-developed algorithms (based on ray tracing) for 10.0 mm and 5.0 mm pupils. Comparisons between preoperative and postoperative measurements and across the groups were made for individual Zernike terms and root-mean-square (RMS) wavefront error.

RESULTS: The RMS (excluding tilt and defocus) did not change in the AcrySof IQ group and increased significantly in the Tecnis group with the 10.0 mm and 5.0 mm pupil diameters. Spherical aberration and coma-like terms did not change significantly; however, vertical astigmatism, vertical trefoil, and vertical tetrafoil changed significantly with surgery with the 10.0 mm and 5.0 mm pupil diameters ($P<.0005$). The induced wave aberration pattern for 3rd- and higher-order aberrations consistently showed a superior lobe, resulting from a combination of positive vertical trefoil (Z_3^{-3}) and negative tetrafoil (Z_4^4). The mean vertical astigmatism increased by 2.47 μm ± 1.49 (SD) and 1.74 ± 1.44 μm, vertical trefoil increased by 1.81 ± 1.19 μm and 1.20 ± 1.34 μm, and tetrafoil increased by −1.10 ± 0.78 μm and −0.89 ± 0.68 μm in the Tecnis group and AcrySof IQ group, respectively. There were no significant differences between the corneal aberrations in the 2 postoperative groups, although there was a tendency toward more terms or orders changing statistically significantly in the Tecnis group, which had slightly higher amounts of induced aberrations.

CONCLUSIONS: Cataract surgery with a small superior incision induced consistent and significant changes in several corneal Zernike terms (vertical astigmatism, trefoil, and tetrafoil), resulting in a significantly increased overall corneal RMS wavefront error. These results can be used to improve predictions of optical performance with new IOL designs using computer eye models and identify the potentially different impact of incision strategies on cataract surgery.

J Cataract Refract Surg 2007; 33:217–226 © 2007 ASCRS and ESCRS

Cataract surgery has advanced considerably in the past few years. Among other advances, foldable intraocular lenses (IOLs) allow implantation through small incisions and more sophisticated optical surfaces give better control of optical outcomes. In particular, monofocal IOLs with aspherical surfaces (resulting in negative spherical aberration) have been introduced, with the aim of balancing the positive corneal spherical aberration.[1] These IOLs reduce the amount of spherical aberration with respect to conventional spherical IOLs,[2,3] and some studies report contrast sensitivity improvements over results with spherical IOLs.[4,5] Higher-order aberrations (HOAs) of the cornea (ie, 3rd- and higher-order terms) and the geometry and positioning of the IOL all contribute to final optical quality. The benefit of correcting spherical aberration relies on relatively small contributions of other factors that potentially

Published by Elsevier Inc.

0886-3350/07/$-see front matter
doi:10.1016/j.jcrs.2006.10.021

increase HOAs[6]; these include lens tilt and decentration[7] and corneal irregularities.

Several studies[8,9] discuss the potential role of the corneal incision in altering corneal shape. It is well known that the corneal incision modifies corneal astigmatism by about 1.00 diopter (D), and the location of the incision is often created in the steepest meridian with the aim of reducing corneal astigmatism. Hayashi et al.[10] evaluated irregular astigmatism using Fourier analysis of corneal elevation maps from videokeratography preoperatively and after implantation of silicone, acrylic and poly(methyl methacrylate) (PMMA) IOLs through 3.5 mm, 4.1 mm, and 6.5 mm incisions in 240 eyes. They found that "high-order irregularities" increased after surgery in all 3 groups but that the increase persisted 3 months after surgery only in the 6.5 mm group. Guirao et al.[11] performed one of the first studies reporting corneal aberrations after cataract surgery (extracapsular cataract extraction with a 6.0 mm incision and PMMA IOL implantation). A comparison with corneal aberrations in a healthy age-matched control group (20 eyes in each group) showed no statistically significant differences for 4.0 mm pupil diameters. Barbero et al.[12] studied total and corneal aberrations in 9 eyes after cataract surgery (phacoemulsification with implantation of acrylic spherical IOLs through a 4.1 mm incision). They found slightly higher (but not statistically significant) corneal aberrations in postoperative eyes than in a young control group (for 5.0 mm); however, all eyes measured preoperatively and postoperatively showed larger amounts of 3rd- and higher-order corneal aberrations after surgery. One of the most comprehensive studies of changes in corneal aberrations after small-incision cataract surgery is that of Guirao et al.[13] They measured corneal aberrations (for 6.0 mm pupils) in the same eyes before and after implantation of monofocal foldable spherical IOLs (silicone and acrylic) through a 3.5 mm superior, nasal, or temporal incision. Although a major conclusion was that a small incision does not systematically degrade anterior corneal optical quality, there were changes in some aberrations and a significant increase in astigmatism and trefoil.

The amount and orientation of the aberrations induced depend on the surgical meridian and incision location. Pesudovs et al.[14] studied the effect of 2 types of spherical IOLs (PMMA and acrylic) and incision locations (corneal and scleral) on total wave aberrations, measured with a Hartmann-Shack wavefront sensor. Aberrations in 20 eyes (PMMA IOL, scleral incision), 21 eyes (acrylic IOL, scleral incision), and 16 eyes (acrylic IOL, corneal incision) were compared with those in an age-matched control group. The authors found that scleral incisions induced fewer aberrations than corneal incisions. The PMMA–scleral group (incision size 5.2 mm) had fewer aberrations than the acrylic–corneal group (incision size 3.5 mm) and aberrations comparable to those in the control group. They report higher amounts of total tetrafoil in the acrylic–corneal group than in the phakic group.

In the present study, we report corneal aberrations over 10.0 mm and 5.0 mm diameters in patients who had implantation of recently introduced aspherical IOLs (Tecnis Z9000, Advanced Medical Optics; AcrySof IQ SN60WF, Alcon Research Labs). By measuring aberrations over a large pupil diameter, we were able to assess to a greater extent the optical changes produced on the anterior cornea, not limited by the eye's pupil size. This analysis is relevant in the understanding of corneal biomechanical changes after an incision and in the assessment of off-axis optical quality. We also present data for 5.0 mm pupils to account for changes potentially more relevant to visual function. The surgical protocol was identical in all eyes, including incision size (3.2 mm) and location (superior), to avoid confounding factors associated with differences in incision architecture. In this context, the purposes of this work were to assess (1) whether there is a systematic increase in corneal aberrations after small-incision cataract surgery and obtain an average map of induced corneal aberrations with this procedure; (2) whether there are corneal differences associated with the type of IOL implanted. This information will be of great use to simulate surgical outcomes using eye models (in which the average map of induced aberrations can be incorporated); understand optical performance in eyes implanted with IOLs, particularly with new designs aimed at reducing the amount of aberrations; and evaluate which aspects of surgery should be improved.

PATIENTS AND METHODS

Forty-three eyes of 23 patients with cataract were studied. Patients were invited to participate in the study and to randomly

Accepted for publication October 1, 2006.

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No author has a financial or proprietary interest in any material or method mentioned.

Supported by grants GR/SAL/0387/2004, Comunidad Autómoma de Madrid and BFM2002-02638 and FIS2005-04382, Ministerio de Educación y Ciencia, and a European Young Investigator Award (Dr. Marcos).

Alcon Research Labs supplied the AcrySof IQ intraocular lenses and Monarch II injector, and Pharmacia supplied the Tecnis intraocular lenses and AMO injector.

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have bilateral implantation of 1 of 2 types of aspherical IOLs (Tecnis, Z9000 or AcrySof IQ SN60WF). Inclusion criteria included good general health, no ocular pathology, astigmatism less than 2.50 D, younger than 75 years old, and no complications after surgery. All patients recruited before surgery completed the study. All enrolled patients were informed of the nature of the study and signed consent forms. Protocols were approved by institutional review boards and ethical committees and adhered to the tenets of the Declaration of Helsinki.

Clinical examination at the hospital (Fundación Jiménez Díaz) included best spectacle-corrected visual acuity (BSCVA), uncorrected visual acuity (UCVA), refractometry, keratometry, ultrasound biometry, tonometry, biomicroscopy, and indirect ophthalmoscopy. Corneal diameters were obtained from infrared-front illumination images using custom algorithms of limbus detection and ellipse fitting. Table 1 shows a profile of the patients.

All procedures were performed by the same surgeon (I.J-A.) on an outpatient basis using topical anesthesia. The same procedure was used to implant both types of IOLs. A 3.2 mm superior clear corneal incision (approximately 1.0 mm from the limbus) and a paracentesis were created with a surgical knife. A 6.0 mm continuous curvilinear capsulorhexis was made under an ophthalmic viscosurgical device (OVD). Phacoemulsification of the lens was performed with the Venturi Millennium system (Bausch & Lomb). After the cortical material was removed, the capsules were cleaned with the automatic irrigation/aspiration straight tip. The Tecnis IOL was implanted using the AMO Silver Series II injector and the AcrySof IQ IOL, using the Monarch II injector. Once the OVD was removed, the incision was closed by hydration without sutures. Postoperatively, patients were treated with a combination of dexamethasone and tobramycin drops for 4 weeks.

Anterior Corneal Aberrations

Corneal topography was measured by videokeratoscopy (Atlas, Humphrey-Zeiss). Elevation maps measured with respect to a reference plane tangential to the corneal vertex were exported as ASCII files to custom software written in Matlab (Mathworks). Aberrations were obtained using the Zemax optical design program (Focus Software), launched from a visual interface programmed in Visual Basic. In brief, corneal ray aberrations were obtained by virtual ray tracing on the anterior corneal surface, after which wave aberrations were obtained by modal fitting of ray aberrations to the derivatives of Zernike polynomial expansions up to the 7th order. A detailed description of the procedure, computations, and validation of the techniques has been presented.[15–17] In the present study, corneal aberrations were obtained for 10.0 mm pupil diameters and referred to the corneal reflex. In addition, the corneal Zernike terms, obtained for 10.0 mm, were rescaled for 5.0 mm pupils.

Corneal topography was obtained preoperatively (fewer than 10 days before surgery) and postoperatively (at least 45 days after surgery). Corneal aberrations are expressed as individual Zernike coefficients (ie, 4th-order spherical aberration, vertical trefoil), as the root mean square (RMS) of a combination of some terms (ie, coma like, trefoil), or as the RMS of Zernike orders (ie, 3rd- and higher-order RMS, 3rd-order RMS). Induced aberrations were obtained as the difference between postoperative and preoperative aberrations for each Zernike term.

Statistical Analysis

Corneal aberrations were compared before and after surgery in both groups of patients, and statistical differences were tested using a paired *t* test for 2-sample comparison. Also, preoperative, postoperative, and induced aberrations were compared across groups, and statistical differences were tested using an unpaired *t* test for 2-sample comparison.

RESULTS

Figure 1 shows typical examples of corneal wave aberration patterns before and after surgery as well as the induced wave aberrations (for 3rd and higher orders; that

Table 1. Profile of patients.

Parameter	Mean ± SD: Acrysof IQ Group (n = 21)	Mean ± SD: Tecnis Group (n = 22)	*P* Value
Age (y)	71.1 ± 3.0	68.0 ± 9.5	.174
Preop SE (D)	−1.26 ± 2.6	−1.59 ± 2.85	.712
Preop astigmatism (D)	0.8 ± 0.7	1.5 ± 0.7	.005*
Corneal diameter @ vertical meridian (mm)†	11.1 ± 0.2	11.05 ± 0.58	.700
Preop corneal astigmatism (D)	0.96 ± 0.68	1.17 ± 0.90	.397
Preop corneal power (D)	44.58 ± 1.30	43.92 ± 1.20	.095
Postop corneal astigmatism (D)	0.92 ± 0.53	1.26 ± 0.63	.072
Postop corneal power (D)	44.60 ± 1.32	43.92 ± 1.28	.105
IOL power (D)	20.6 ± 2.0	21.3 ± 3.4	.428
Time between surgery and postop measurements (d)	115 ± 106	95 ± 64	.472

IOL = intraocular lens; SE = spherical equivalent

*Unpaired *t* test, $P < .05$; significantly different with a confidence interval of 95%

†This parameter, includes 10 AcrySof eyes and 19 Tecnis eyes as images from the other eyes were inadequate to estimate vertical corneal diameter.

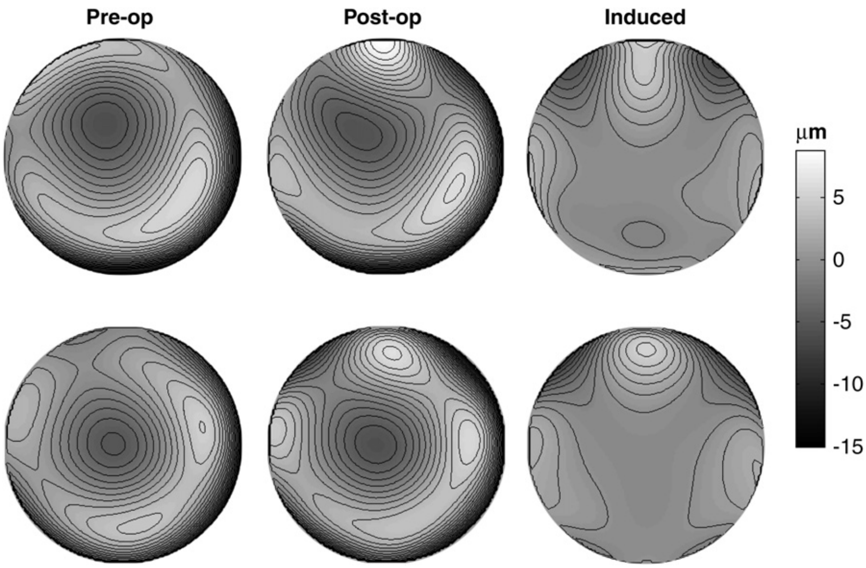

Figure 1. Maps of preoperative corneal aberrations, postoperative corneal aberrations, and induced corneal aberrations (difference between postoperative and preoperative aberrations) in 2 eyes. *Top:* AcrySof IQ IOL. *Bottom:* Tecnis IOL. Data are for 3rd- and higher-order aberrations and a 10.0 mm corneal diameter.

is, excluding tilt, defocus, and astigmatism). The differences between the postoperative and preoperative patterns were consistent across eyes, with a typical superior lobe in the postoperative pattern that was not present in the preoperative pattern. The position of the lobe was consistent with the superior incision. Looking at individual terms, postoperative patterns showed consistently increased vertical astigmatism Z_2^2, increased vertical trefoil Z_3^{-3}, and increased vertical tetrafoil Z_4^4 (toward more negative values). The combination of positive trefoil and negative tetrafoil produced the characteristic superior lobe in the postoperative and induced aberration patterns.

Figure 2 shows preoperative, postoperative, and induced vertical astigmatism, trefoil, tetrafoil, and spherical aberration in all eyes in each group (10.0 mm). Figure 3 shows the RMS, including all terms (except tilt and defocus), in all eyes in each group. Table 2 shows the relevant mean preoperative and postoperative individual Zernike coefficient and RMS (for different orders and terms) for 10.0 and 5.0 mm pupils in the AcrySof IQ group and Tecnis group. Preoperative aberration values, except for vertical coma with a 10.0 mm pupil, were not statistically different between groups. In the AcrySof group, there were statistically significant preoperative and postoperative differences in vertical astigmatism, vertical trefoil, and vertical tetrafoil (for 10.0 mm and 5.0 mm pupils) as well as other 6 and 10 higher-order terms, respectively (not shown in the graph). In the Tecnis group, there were statistically significant preoperative and postoperative differences in vertical astigmatism, vertical trefoil, and tetrafoil (for 10.0 mm and 5.0 mm pupils) as well as other 8 and 6 higher-order terms (not shown in the graphs). There were no statistically significant differences in spherical aberration or coma-like terms. In terms of RMS, there were statistically significant differences in 3rd- and higher-order terms and 5th- and higher-order terms in the AcrySof IQ group and in 3rd- and higher-order, 3rd-order alone, 4th- and higher-order, 4th-order alone, 5th- and higher-order, and trefoil in the Tecnis group for 10.0 mm and 5.0 mm pupils. Spherical aberration and coma RMS did not change significantly in either group. Although the Tecnis group had a significant increase in more terms and orders than the AcrySof IQ group and the postoperative values in the Tecnis group were slightly higher, the differences in postoperative values between groups were not statistically significant.

Despite the increase in certain aberrations, in general, corneal aberrations preoperatively correlated well with corneal aberrations postoperatively. In AcrySof IQ eyes, the correlation between all terms (except tilt) preoperatively and postoperatively was positive and statistically significant in all eyes ($P<.0001$). The mean slope across eyes was 0.91 $\pm$ 0.21 (SD) and the correlation coefficient (R), 0.88 $\pm$ 0.13. When defocus was excluded, the correlation was significant in all except 2 eyes. When defocus and astigmatism were excluded, the correlation was significant in all except 4 eyes. In Tecnis eyes, the correlation between all terms (except tilt) preoperatively and postoperatively was positive and statistically significant in all eyes except eyes 17, 18, and 20 ($P<.0001$). The mean slope across eyes (excluding those 3 eyes) was 0.94 $\pm$ 0.22 and R, 0.84 $\pm$ 0.099. When defocus, astigmatism, or both were excluded, the correlation was still significant in all except 5 eyes. Figure 4 shows the correlation between preoperative and postoperative

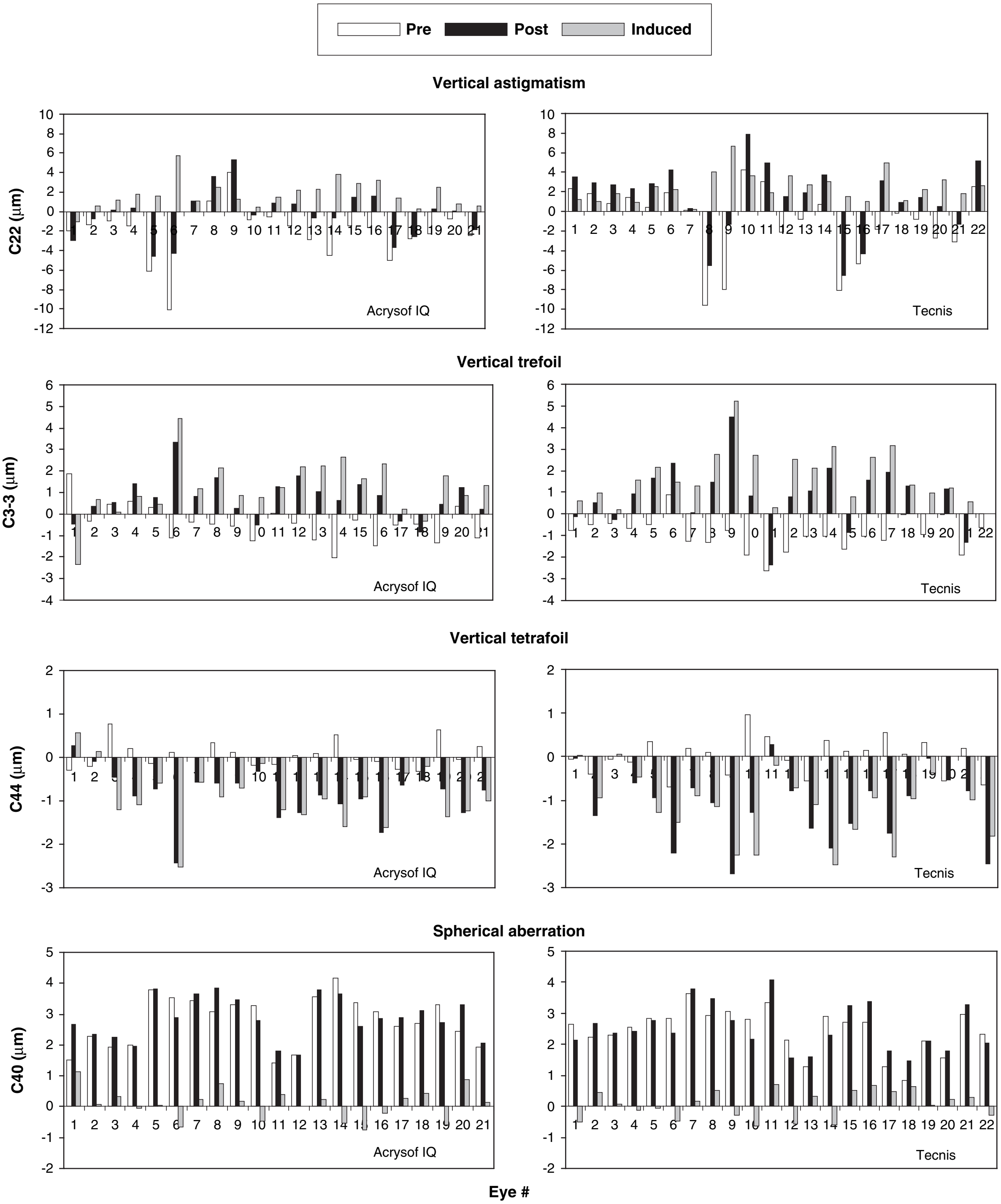

Figure 2. Preoperative, postoperative, and induced abberrations in all eyes in the study: 0/90° corneal astigmatic term, vertical trefoil, vertical tetrafoil, and spherical aberration. Data are for a 10.0 mm corneal diameter.

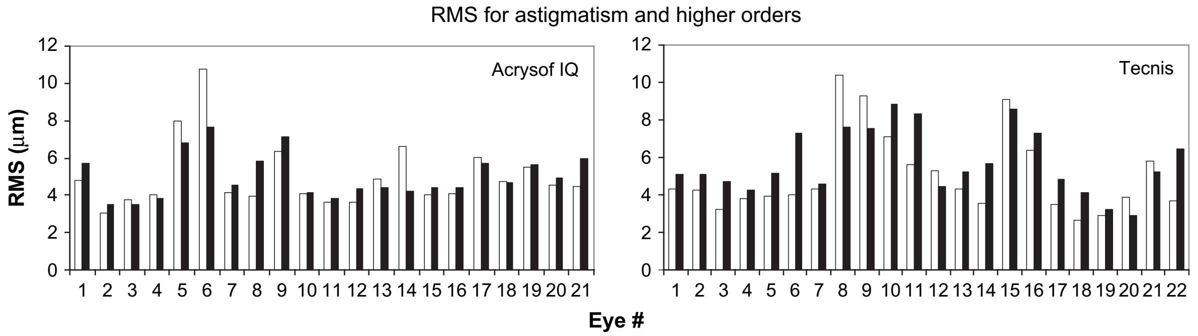

Figure 3. Preoperative and postoperative corneal RMS wavefront error in all eyes in the study. Data are for a 10.0 mm corneal diameter.

Zernike coefficients in 2 typical eyes. The correlation was preserved primarily because spherical aberration and coma, major contributors to HOAs, do not change significantly with surgery. When analyzing correlations preoperatively and postoperatively (across all eyes), there was no correlation for 21 of the 35 Zernike coefficients in the AcrySof IQ group and 18 of 35 in the Tecnis group ($P>.05$). Figure 5 shows the correlation between preoperative and postoperative values for spherical aberration, vertical trefoil, and vertical tetrafoil.

To average individual differences and find the typical changes in corneal aberrations induced by surgery, the mean induced wave aberration patterns were calculated. These are shown in Figure 6, and the corresponding coefficients are shown in Table 3 for 10.0 mm and 5.0 mm pupils. Table 3 shows the Zernike terms that were statistically significantly different from zero (primarily vertical astigmatism, trefoil, and tetrafoil). Designers of computer eye models to test the effects of IOLs in optical performance can incorporate these induced aberrations in their models, adding them to the preoperative corneal aberrations.

DISCUSSION

We found that small-incision cataract surgery in patients with 2 types of aspherical IOLs induced consistent and highly statistically significant changes in astigmatism and tetrafoil. The procedure did not induce significant changes in spherical aberration or coma terms. Interestingly, highly statistically significant differences were found

Table 2. Preoperative and postoperative RMS of the corneal wave aberration and relevant Zernike terms for the 2 groups of patients for 10.0 mm and 5.0 mm diameters. Statistical analysis corresponds to comparisons between groups (for preoperative and postoperative measurements) and between preoperative and postoperative measurements (in each group).

RMS/Zernike Terms (μm)	Pre (10.0 mm)			Post (10.0 mm)			Differences Pre/Post P Value† (10.0 mm)	
	Tecnis	AcrySof IQ	P Value*	Tecnis	AcrySof IQ	P Value*	Tecnis	AcrySof IQ
RMS all (no defocus or tilt)	5.06 ± 2.10	5.01 ± 1.78	.93	5.75 ± 1.72	5.01 ± 1.19	.11	0.0404‡	.98
RMS 3rd & higher	3.54 ± 0.66	3.83 ± 0.53	.12	4.31 ± 1.17	4.29 ± 0.68	.95	0.0016‡	.004‡
RMS 3rd	2.18 ± 0.80	2.29 ± 0.74	.65	2.78 ± 1.11	2.57 ± 0.99	.52	0.015‡	.20
RMS 4th	2.57 ± 0.64	2.86 ± 0.78	.19	3.01 ± 0.76	3.16 ± 0.60	.48	0.0006‡	.0095‡
RMS 4th & higher	2.69 ± 0.62	2.95 ± 0.75	.23	3.22 ± 0.80	3.31 ± 0.59	.66	0.0005‡	.0019‡
RMS 5th & higher	0.68 ± 0.34	0.61 ± 0.28	.47	1.07 ± 0.46	0.96 ± 0.21	.29	0.005‡	<.0001‡
RMS spherical	2.46 ± 0.69	2.79 ± 0.81	.16	2.54 ± 0.75	2.88 ± 0.68	.13	0.43	.41
RMS trefoil	1.22 ± 0.71	0.99 ± 0.48	.23	1.85 ± 1.17	1.33 ± 0.72	.091	0.008‡	.080
RMS coma	1.68 ± 0.75	1.95 ± 0.87	.28	1.82 ± 0.93	2.10 ± 0.95	.338	0.43	.46
Z_2^2	−1.05 ± 3.78	−2.07 ± 2.79	.32	1.42 ± 3.52	−0.33 ± 2.44	.066	<0.0001‡	<.0001‡
Z_3^{-3}	−0.95 ± 0.76	−0.44 ± 0.87	.0456‡	0.86 ± 1.42	0.76 ± 0.94	.79	<0.0001‡	.0005‡
Z_4^0	2.45 ± 0.70	2.78 ± 0.81	.16	2.53 ± 0.74	2.87 ± 0.68	.12	0.45	.42
Z_4^4	0.01 ± 0.43	0.06 ± 0.31	.66	−1.09 ± 0.82	−0.83 ± 0.58	.25	<0.0001‡	<.0001‡

RMS = root mean square; Z_2^2 = astigmatism at 0/90 degrees; Z_3^{-3} = vertical trefoil; Z_4^0 = spherical 4th-order aberration; Z_4^4 = vertical tetrafoil

*Unpaired *t* test

†Paired *t* test

‡$P<.05$, significantly different with a confidence interval of 95%

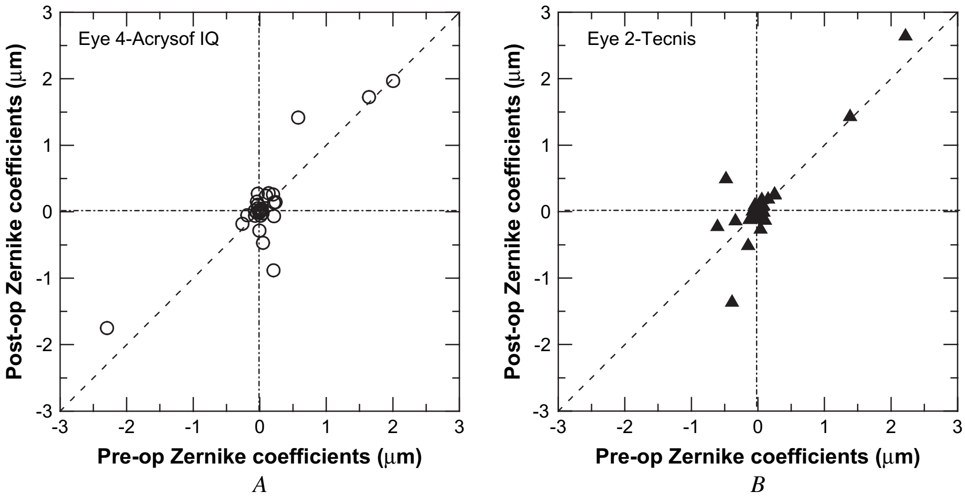

Figure 4. Correlation between preoperative and postoperative corneal Zernike coefficients (3rd order and higher) in 2 eyes. *A*: Eye 4 with an AcrySof IQ IOL. *B*: Eye 2 with a Tecnis IOL. Slopes are 0.91 and 1.08, and correlation coefficients are 0.89 and 0.88 for (*A*) and (*B*), respectively. Dashed lines indicate $y = x$. Data are for a 10.0 mm corneal diameter.

not only in the largest area but also for pupil diameters (5.0 mm) potentially relevant to vision.

Changes in corneal astigmatism are well known, and changes in corneal trefoil have also been reported. Our conclusions are stronger than those of Guirao et al.,[13] likely because in our study, all eyes had superior incisions, which allows higher statistical power. Although Guirao et al. do not report changes in tetrafoil term, we found that tetrafoil was consistently induced in all patients, with similar amounts (and opposite signs) than trefoil, In addition, along with vertical trefoil, it was responsible for the characteristic pattern of induced aberrations. To our knowledge, only Pesudovs et al.[14] have reported the presence of ocular tetrafoil in a group of eyes with a spherical IOL implanted through a corneal incision (not with the same IOL implanted through a scleral incision). Because only total (and not corneal) aberrations were measured, they could not confirm the origin of this aberration. In addition, Guirao et al. used a different phakic group to perform the comparisons, whereas we computed the actual aberrations induced by performing measurements in the same eyes preoperatively and postoperatively.

Table 2 (*cont.*)

Pre (5.0 mm)			Post (5.0 mm)			Differences Pre/Post *P* Value† (5.0 mm)	
Tecnis	AcrySof IQ	*P* Value*	Tecnis	AcrySof IQ	*P* Value*	Tecnis	AcrySof IQ
0.77 ± 0.44	0.64 ± 0.40	.33	1.00 ± 0.35	0.82 ± 0.33	.09	.023‡	.08
0.29 ± 0.12	0.27 ± 0.06	.35	0.46 ± 0.18	0.43 ± 0.11	.53	.003‡	<.0001‡
0.24 ± 0.12	0.21 ± 0.07	.37	0.40 ± 0.19	0.36 ± 0.13	.44	.006‡	<.0001‡
0.16 ± 0.05	0.14 ± 0.05	.41	0.20 ± 0.05	0.21 ± 0.04	.72	.002‡	.0001‡
0.16 ± 0.06	0.15 ± 0.05	.38	0.21 ± 0.05	0.22 ± 0.04	.63	.0007‡	<.0001‡
0.03 ± 0.02	0.03 ± 0.01	.20	0.06 ± 0.02	0.07 ± 0.02	.28	<.0001‡	<.0001‡
0.13 ± 0.05	0.13 ± 0.05	.67	0.11 ± 0.06	0.12 ± 0.05	.61	.065	.52
0.16 ± 0.13	0.10 ± 0.06	.08	0.35 ± 0.20	0.32 ± 0.13	.54	.002‡	<.0001‡
0.16 ± 0.07	0.17 ± 0.10	.88	0.17 ± 0.09	0.16 ± 0.07	.66	.76	.58
−0.05 ± 0.79	−0.36 ± 0.56	.13	0.57 ± 0.67	0.26 ± 0.62	.12	<.0001‡	.002‡
−0.09 ± 0.15	−0.04 ± 0.08	.18	0.26 ± 0.22	0.24 ± 0.13	.74	<.0001‡	<.0001‡
0.13 ± 0.05	0.13 ± 0.05	.66	0.11 ± 0.06	0.12 ± 0.05	.57	.067	.52
0.00 ± 0.03	0.00 ± 0.03	.63	−0.12 ± 0.07	−0.10 ± 0.06	.45	<.0001‡	<.0001‡

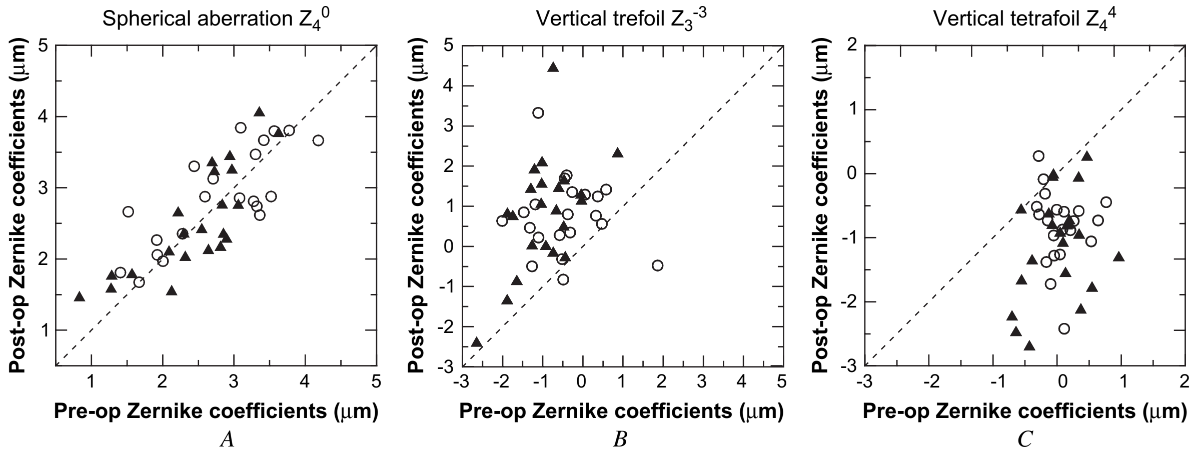

Figure 5. Correlation between preoperative and postoperative aberrations for all eyes. *A:* Corneal spherical aberration. *B:* Vertical trefoil. *C:* Vertical tetrafoil. Open circles represent eyes with the AcrySof IQ IOL and solid triangles, eyes with the Tecnis IOL. Dashed line corresponds to $y = x$. Data are for a 10.0 mm corneal diameter.

We confirmed that neither spherical aberration nor coma changed significantly with the procedure. As a result, aspherical IOLs designed to compensate for the mean preoperative corneal spherical aberration can work under the assumption that spherical aberration remains practically unchanged. Changes in astigmatism, trefoil, and tetrafoil are not negligible and should be considered in simulations of optical outcomes of cataract surgery. Along with real corneal topographies and IOL design, corneal aberrations induced by the procedure should be considered when trying to predict the outcomes of cataract surgery, being potentially more important than the presence of moderate amounts of IOL tilt and decentration (P. Rosales, et al. IOVS 2006; 47:ARVO E-Abstract 313). The numerical data in Table 2 will help to produce more realistic predictions using eye models. Other potential changes, expected to be minor, refer to the posterior corneal surface.

We found slight differences in the change between preoperative and postoperative aberrations with the 2 types of aspherical lenses, with the Tecnis IOLs showing a slightly higher increase in aberrations. Most differences between IOLs were not statistically significant and may not have visual consequences. Corneal diameters (particularly along

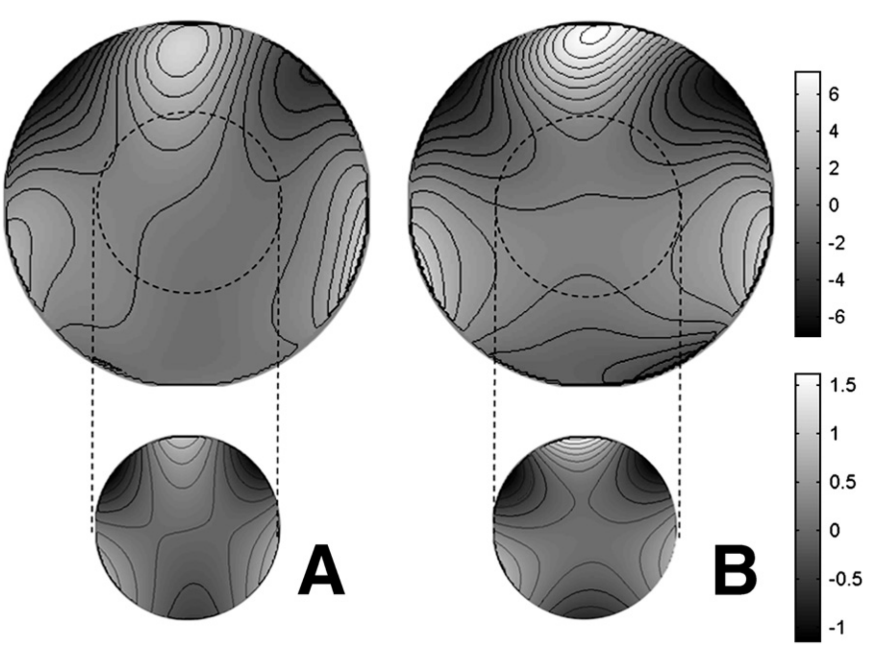

Figure 6. Mean induced corneal wave aberration maps for 3rd- and higher-order aberrations. *A*: Eyes with the AcrySof IQ IOL. *B:* Eyes with the Tecnis IOL. Top maps are for 10.0 mm diameters, with contour lines every 1.00 μm. Bottom maps are for 5.0 mm diameters, with contour lines every 0.25 μm. Scale bars are different for each diameter. The 5.0 mm area is highlighted in the 10.0 mm map.

Table 3. Induced corneal aberrations (Zernike terms) in each group for 10.0 mm and 5.0 mm diameters and corresponding significance when comparing preoperative and postoperative terms.

	Tecnis (10.0 mm)		Tecnis (5.0 mm)		AcrySof IQ (10.0 mm)		AcrySof IQ (5.0 mm)	
Zernike Coeff	Mean ± SD (μm)	*P* Value	Mean ± SD (μm)	*P* Value	Mean ± SD (μm)	*P* Value	Mean ± SD (μm)	*P* Value
Z_1^{-1}	−0.73 ± 2.25	.143	−0.079 ± 0.353	.30	1.21 ± 2.32	.027*	0.228 ± 0.297	.002*
Z_1^{1}	0.06 ± 3.43	.936	−0.024 ± 0.268	.68	−0.35 ± 3.40	.642	0.195 ± 1.372	.52
Z_2^{-2}	−0.12 ± 1.11	.609	0.035 ± 0.218	.45	0.00 ± 0.75	.9892	0.083 ± 0.336	.27
Z_2^{0}	−0.11 ± 1.06	.641	0.019 ± 0.060	.15	0.11 ± 1.11	.656	0.003 ± 0.043	.78
Z_2^{2}	2.47 ± 1.50	<.0001*	0.623 ± 0.390	<.0001*	1.74 ± 1.44	<.0001*	0.618 ± 0.257	<.0001*
Z_3^{-3}	1.81 ± 1.19	<.0001*	0.344 ± 0.240	<.0001*	1.20 ± 1.34	.0006*	0.277 ± 0.125	<.0001*
Z_3^{-1}	−0.17 ± 1.13	.485	−0.036 ± 0.109	.13	0.37 ± 1.24	.190	0.068 ± 0.089	.002*
Z_3^{1}	0.05 ± 1.66	.899	−0.003 ± 0.103	.87	−0.41 ± 1.08	.095	−0.023 ± 0.083	.23
Z_3^{3}	−0.23 ± 1.02	.302	−0.084 ± 0.174	.034*	−0.07 ± 0.86	.696	−0.062 ± 0.208	.18
Z_4^{-4}	0.00 ± 0.52	.998	−0.054 ± 0.071	.0018*	−0.08 ± 0.42	.416	−0.028 ± 0.109	.26
Z_4^{-2}	−0.17 ± 0.31	.017*	0.004 ± 0.026	.49	−0.13 ± 0.30	.064	−0.005 ± 0.030	.44
Z_4^{0}	0.07 ± 0.45	.448	−0.021 ± 0.051	.067	0.09 ± 0.50	.417	−0.005 ± 0.034	.51
Z_4^{2}	−0.08 ± 0.61	.567	0.008 ± 0.047	.44	−0.24 ± 0.65	.103	−0.017 ± 0.048	.11
Z_4^{4}	−1.10 ± 0.79	<.0001*	−0.121 ± 0.074	<.0001*	−0.89 ± 0.68	<.0001*	−0.101 ± 0.058	<.0001*
Z_5^{-5}	−0.19 ± 0.49	.092	−0.041 ± 0.022	<.0001*	−0.24 ± 0.26	.0004*	−0.039 ± 0.028	<.0001*
Z_5^{-3}	−0.20 ± 0.41	.036*	−0.011 ± 0.020	.014*	−0.18 ± 0.38	.049*	−0.014 ± 0.016	.0005*
Z_5^{-1}	0.12 ± 0.39	.169	−0.004 ± 0.016	.29	0.04 ± 0.33	.596	−0.006 ± 0.015	.07
Z_5^{1}	−0.02 ± 0.20	.716	0.003 ± 0.016	.46	−0.06 ± 0.16	.104	−0.002 ± 0.011	.38
Z_5^{3}	0.14 ± 0.22	.008*	0.003 ± 0.013	.33	0.09 ± 0.23	.077	0.005 ± 0.016	.18
Z_5^{5}	−0.06 ± 0.40	.484	0.011 ± 0.029	.10	0.05 ± 0.29	.423	0.013 ± 0.042	.17
Z_6^{-6}	−0.06 ± 0.36	.472	−0.001 ± 0.006	.47	−0.01 ± 0.22	.877	0.000 ± 0.003	.88
Z_6^{-4}	0.19 ± 0.21	.0003*	0.003 ± 0.003	.0003*	0.08 ± 0.32	.252	0.001 ± 0.005	.25
Z_6^{-2}	−0.05 ± 0.12	.059	−0.001 ± 0.002	.059	−0.01 ± 0.11	.627	0.000 ± 0.002	.63
Z_6^{0}	0.09 ± 0.20	.046*	0.001 ± 0.003	.045*	0.04 ± 0.14	.237	0.001 ± 0.002	.24
Z_6^{2}	−0.05 ± 0.22	.347	−0.001 ± 0.003	.34	0.01 ± 0.18	.844	0.000 ± 0.003	.84
Z_6^{4}	0.19 ± 0.29	.0063*	0.003 ± 0.005	.006*	0.16 ± 0.17	.0004*	0.003 ± 0.003	.0004*
Z_6^{6}	0.13 ± 0.37	.118	0.002 ± 0.006	.12	0.11 ± 0.25	.051	0.002 ± 0.004	.051
Z_7^{-7}	−0.03 ± 0.16	.412	0.000 ± 0.001	.41	0.06 ± 0.10	.0146*	0.000 ± 0.001	.015*
Z_7^{-5}	0.21 ± 0.13	<.0001*	0.002 ± 0.001	<.0001*	0.20 ± 0.17	<.0001*	0.002 ± 0.001	<.0001*
Z_7^{-3}	0.03 ± 0.12	.255	0.000 ± 0.001	.25	0.05 ± 0.09	.0155*	0.000 ± 0.001	.015*
Z_7^{-1}	0.05 ± 0.12	.0815	0.000 ± 0.001	.08	0.05 ± 0.10	.043*	0.000 ± 0.001	.043*
Z_7^{1}	−0.02 ± 0.07	.2421	0.000 ± 0.001	.24	0.00 ± 0.08	.885	0.000 ± 0.001	.89
Z_7^{3}	0.01 ± 0.09	.599	0.000 ± 0.001	.5993	−0.01 ± 0.08	.536	0.000 ± 0.001	.54
Z_7^{5}	−0.08 ± 0.15	.024*	−0.001 ± 0.001	.0244*	−0.07 ± 0.22	.163	−0.001 ± 0.002	.16
Z_7^{7}	0.01 ± 0.17	.745	0.000 ± 0.001	.745	0.02 ± 0.15	.487	0.000 ± 0.001	.49

Coeff = coefficient
*Statistically significant ($P<.05$)

the meridian of the incision) were not statistically different between groups; therefore, any difference in outcomes cannot be attributed to differences in the effective incision location (relative to the apex). In addition, we did not find a significant correlation between vertical corneal diameter and induced vertical astigmatism, trefoil, and tetrafoil.

Although the study was designed to follow identical protocols in the 2 groups and the incision size was purposely larger than the minimum values potentially allowed with the 2 injectors used to implant the 2 IOL types (2.2 mm for AcrySof and 2.8 mm for Tecnis), differences may be associated with slight final differences in incision size. The effective incision size after implantation was not measured. However, enlargement of the incision at different steps of the procedure,[18] and particularly differences between injectors,[19] have been reported and may play a role in the observed tendencies.

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