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Postoperative Optical Aberrations in Eyes Implanted With AcrySof Spherical and Aspheric Intraocular Lenses

Luis Cadarso, MD; Ana Iglesias, MD; Alberto Ollero, MD; Begoña Pita, MD; Robert Montés-Micó, PhD

ABSTRACT

PURPOSE: To evaluate and compare optical and visual quality of eyes implanted with spherical and aspheric intraocular lenses (IOLs).

METHODS: Twenty eyes of 17 patients were implanted with the AcrySof Natural IQ aspheric IOL (SN60WF) and 20 eyes of 15 patients were implanted with the AcrySof Natural spherical IOL (SN60AT). Photopic monocular distance best spectacle-corrected visual acuity (BSCVA) was recorded at 6 months postoperatively. Corneal aberrations were measured with the CSO Eyetop topographer, and ocular aberrations were measured with a Hartmann-Shack aberrometer for a 6-mm pupil. Ocular spherical aberration was computed for different pupil diameters (3, 4, 5, and 6 mm).

RESULTS: No statistically significant differences were found between the BSCVA of the AcrySof IQ IOL (0.023 ± 0.004 logMAR) and AcrySof Natural IOL (0.031 ± 0.003 logMAR) ($P = .15$). The corneal higher order aberrations showed no statistically significant differences between groups ($P > .1$). However, spherical aberration and higher order ocular aberrations in the AcrySof IQ eyes were lower than eyes implanted with the AcrySof Natural IOL ($P < .01$). A statistically significant increase in the spherical aberration coefficient with pupil diameter was found only for the spherical IOL group ($P = .0023$). Statistically significant differences in the spherical aberration coefficient were found between groups at all pupil diameters ($P < .001$).

CONCLUSIONS: A significant reduction in ocular spherical aberration was noted after AcrySof IQ IOL implantation at all pupil diameters compared to the spherical IOL, although photopic BSCVA between groups remained similar. [*J Refract Surg.* 2008;24:811-816.]

The optical quality of the eye is determined by the combination of corneal and lens aberrations. Combination of both surfaces is important to achieve the best optical quality of the whole eye. An excellent combination of both elements is the compensation of positive spherical aberration in the first surface of the cornea by negative spherical aberration in the lens.¹ However, it has been reported that when the eye ages its optical quality becomes worse, as the source of this degradation is the loss of balance between corneal and lens aberrations.² Brunette et al³ described the change in optical aberrations with age. They suggested that changes in lens surface profiles seem to be responsible for most of the increases in aberrations that occur with age. The shift of the spherical aberration of the lens towards less negative or even more positive values⁴ combined with the positive corneal spherical aberration² provokes the decrease in optical quality of the eye with age.

After cataract or clear lens extraction the lens is replaced by an artificial intraocular lens (IOL). The optical quality of the eye is now determined by the combination of corneal and IOL aberrations. Eyes implanted with spherical IOLs showed a reduction in the optical quality (increasing total aberrations and reduction of the modulation transfer function [MTF]),^{5,6} caused, in part, by the increased positive spherical aberration of the IOL. An aspheric IOL with negative spherical aberration is needed to compensate for the positive spherical aberration of the cornea. Recent studies, in which aspheric IOLs were implanted, have shown discrepancies in relation to improved visual performance relative to spherical IOLs.⁷⁻¹¹ Centration and tilt of the IOL as well as inter-subject variability of

From Clinica Cadarso, Vigo (Cadarso, Iglesias, Ollero, Pita); and the Optics Department, Faculty of Physics, University of Valencia (Montés-Micó), Spain.

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Correspondence: Luis Cadarso, MD, Clinica Cadarso, C/ Urzaiz n° 27 2° C, 36201 Vigo (Spain). Tel: 34 986 44 99 20; Fax: 34 986 44 71 28; E-mail: luis.cadarso@clinicacadarso.com

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the corneal spherical aberration play a significant role in explaining these previous results. Another important factor to consider in aspheric IOLs is the spherical aberration of the IOL itself. Different negative values of spherical aberration of the aspheric IOL may result in different visual outcomes.

The AcrySof Natural IQ (Alcon Laboratories Inc, Ft Worth, Tex) is an aspheric IOL with negative spherical aberration designed to reduce the total amount of ocular spherical aberration when implanted after cataract or clear lens extraction. This new IOL, with less negative spherical aberration than other aspheric IOLs, has been developed to improve the visual outcomes achieved in spherical and other aspheric IOL designs. The objective of the present study is to assess the optical and visual quality of eyes implanted with the AcrySof IQ aspheric IOL and to compare results with those found in eyes implanted with spherical IOLs.

PATIENTS AND METHODS

Twenty eyes of 17 patients (mean age: 75.9 ± 1.9 years, range: 60 to 89 years) with cataracts who presented for visual examination were randomly selected to participate in this study and implanted with the AcrySof Natural IQ aspheric IOL (SN60WF model). Twenty eyes of 15 patients (mean age: 74.2 ± 2.4 years, range: 56 to 85 years) with cataract implanted with the AcrySof Natural spherical IOL (SN60AT) were evaluated for comparative purposes. Surgery was performed at the Clínica Cadarso (Vigo, Spain). Inclusion criteria were age between 55 and 90 years, good general health, no ocular pathology, and no complications during surgery. Exclusion criteria were history of glaucoma or retinal detachment, corneal disease, previous corneal or intraocular surgery, abnormal iris, pupil deformation, macular degeneration or retinopathy, neuro-ophthalmic diseases, and history of ocular inflammation.

All patients underwent phacoemulsification with the Infiti Vision System (Alcon Laboratories Inc) using topical anesthesia and a clear corneal 2.75-mm incision by one experienced surgeon (L.C.). Phacoemulsification was followed by irrigation and aspiration of the cortex and IOL implantation in the capsular bag. The targeted refraction was emmetropia. Postoperatively, patients were treated with a combination of antibiotic and corticosteroid drops (dexamethasone and tobramycin) for 4 weeks. No complications occurred in any case. The tenets of the Declaration of Helsinki were followed in this research. Informed consent was obtained from all patients after the nature and possible consequences of the study were explained. Institutional Review Board approval was obtained.

The AcrySof Natural IQ aspheric IOL is a single-piece

IOL made of hydrophobic acrylic material with ultraviolet and blue light filtration and a refractive index of 1.55. The posterior surface of the IOL has the aspheric design to reduce whole eye spherical aberration (IOL negative spherical aberration of $-0.20 \mu\text{m}$ for a 6-mm pupil) (data on file, Alcon Laboratories Inc, Ft Worth, Tex). The overall diameter of the lens is 13.0 mm and the optical diameter is 6.0 mm. Lens power varied from +18.00 to +23.50 diopters (D). The AcrySof Natural spherical IOL is structurally identical to the AcrySof Natural IQ IOL except for the aspheric design, which results in approximately 9% less central thickness. Lens power varied from +17.00 to +23.50 D.

Patients were scheduled for clinical evaluation preoperatively and 1 day, 1 week, and 1, 3, and 6 months postoperatively. Standard ophthalmologic examination included manifest refraction, best spectacle-corrected visual acuity (BSCVA), slit-lamp microscopy, Goldmann applanation tonometry, and binocular indirect ophthalmoscopy. Best spectacle-corrected visual acuity measurement was performed by means of the logarithm of the minimum angle of resolution (logMAR) acuity charts under photopic conditions (85 cd/m^2). Corneal aberrometry was performed using the CSO Eyetop topographer (CSO, Florence, Italy). Ocular wavefront aberrations were measured with the LADARWave Hartmann-Shack aberrometer (Alcon Laboratories Inc). Zernike coefficients were used to calculate the corneal and ocular aberrations, represented by the root-mean-square (RMS) of higher order aberrations (Z_n^i , $n \geq 3$), spherical aberration coefficient (Z_4^0), and RMS of coma-like aberrations ($Z_3^{\pm 1}$ and $Z_5^{\pm 1}$) for a 6-mm pupil. Ocular spherical aberration coefficient (Z_4^0) was computed for 3-, 4-, 5-, and 6-mm pupil diameters to assess differences between IOLs at various pupil diameters.

All postoperative examinations were performed at 6 months after implantation by one ophthalmic technician who was unaware of the objective of the study. Data analysis was performed using SPSS for Windows version 12.0 (SPSS Inc, Chicago, Ill). Normality was checked by the Shapiro-Wilk test, and the Mann-Whitney U test was performed to compare differences in BSCVA and higher order aberrations between both groups. Ocular spherical aberration changes with pupil diameter were evaluated using analysis of variance one-way test. Differences were considered statistically significant at $P < .01$ (ie, at the 1% level).

RESULTS

No intraoperative complications (ie, capsular rupture) occurred in this study. The postoperative clinical course was normal in both groups. Postoperatively, the pupils of all patients were round, without iris trauma,

TABLE 1

Demographics of Patients Who Underwent Implantation of AcrySof Natural IQ and AcrySof Natural IOLs

	AcrySof Natural IQ IOL (SN60WF)	AcrySof Natural IOL (SN60AT)	P Value
No. of eyes	20	20	
Age (y)	75.9±1.9	74.2±2.4	.57
Gender (M/F)	7/10	6/9	.34
IOL power (D)	21.0±1.6	20.6±2.2	.54
Postoperative BSCVA (logMAR)	0.023±0.004	0.031±0.003	.15

BSCVA = best spectacle-corrected visual acuity

and showed a good responsiveness to light. All cases showed good centration and no IOL tilt. No case of posterior capsule opacification at the last follow-up was noted. Patient demographics are shown in Table 1. Postoperative mean spherical equivalent refraction was 0.24 ± 0.31 D and 0.31 ± 0.23 D for the AcrySof IQ and AcrySof Natural groups, respectively.

The mean BSCVA was 0.023 ± 0.004 logMAR in the AcrySof IQ group and 0.031 ± 0.003 logMAR in the AcrySof Natural group. No statistically significant differences were noted between the BSCVA of the AcrySof IQ IOL and AcrySof Natural IOL ($P=.15$). All (100%) patients achieved BSCVA of logMAR 0.1 (20/25) or better in both groups. The percentage of patients who achieved BSCVA of logMAR 0 (20/20) or better was 85% in the AcrySof IQ IOL group and 60% in the AcrySof Natural IOL.

Figure 1 shows the corneal and ocular aberrations found in both groups for a 6-mm pupil. No statistically significant differences were found between groups in relation to higher order, spherical aberration, and coma-like corneal aberrations ($P>.1$) (Table 2). However, when ocular aberrations were analyzed, statistically significant differences were found between groups for spherical aberration and higher order aberrations ($P<.01$) (Table 2). The spherical aberration and higher order ocular aberrations in the AcrySof IQ eyes were lower than eyes implanted with the AcrySof Natural IOL. Ocular spherical aberration in the aspheric IOL group was approximately four times lower than that found in the spherical IOL group. No differences in ocular coma-like aberrations between groups were found. Figure 2 shows the change in the ocular spherical aberration coefficient (Z_4^0) in both groups as a function of the pupil diameter. Analysis of variance one-way test revealed a statistically significant increase in

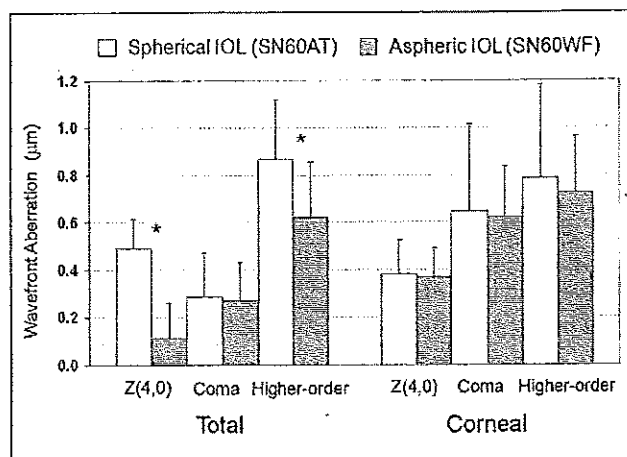


Figure 1. Corneal and ocular aberrations (μm) of the AcrySof Natural IQ and AcrySof Natural IOL groups for a 6-mm pupil. Spherical aberration coefficient (Z_4^0) and root-mean-square (RMS) of higher order aberrations (Z_n , $n \geq 3$) and coma-like aberrations (Z_3^{-1} and Z_3^{-3}). The asterisk indicates statistically significant differences between groups.

the spherical aberration coefficient with pupil diameter only for the spherical IOL group ($P=.0023$). Statistically significant differences in the spherical aberration coefficient were found between groups at all pupil diameters ($P<.001$) (see Fig 2).

DISCUSSION

The present study evaluates the visual and optical outcomes in cataract patients with the AcrySof Natural IQ IOL designed to reduce ocular spherical aberration and compares the results to those in eyes implanted with the spherical AcrySof Natural IOL. Our results revealed no differences between groups in higher order, spherical aberration, and coma-like corneal aberrations. Differences between groups come from the ocular changes and not from the possible surgically induced corneal changes. Significant differences in the ocular measurements are due to intraocular implantation of the different IOLs. Table 2 shows that both groups have comparable corneal aberrations ($P>.1$).

Considering the ocular aberrations, no differences in coma-like aberrations were found between groups ($P>.1$). Dietze and Cox¹² reported that decentered or misaligned aspheric IOLs produce an increase in coma aberration compared to spherical IOLs. Our results showed comparable amounts of coma aberration between groups, which suggests, as was verified with slit-lamp microscopy, no significant decentration or tilt in any case. In contrast, ocular spherical aberration and higher order aberrations were significantly lower for eyes implanted with the AcrySof Natural IQ IOL. The reduction found for higher order aberrations comes from the reduction in the spherical aberration (approx-

TABLE 2

Corneal and Ocular Aberrations of the AcrySof Natural IQ and AcrySof Natural IOL Groups for a 6-mm Pupil

	AcrySof Natural IQ IOL (SN60WF)	AcrySof Natural IOL (SN60AT)	P Value
Higher-order (Z_n , $n \geq 3$)			
Ocular	0.621 ± 0.233	0.870 ± 0.247	.0041*
Corneal	0.724 ± 0.237	0.786 ± 0.395	.2067
Spherical aberration (Z_4^0)			
Ocular	0.114 ± 0.147	0.492 ± 0.122	1.40 × 10 ^{-8*}
Corneal	0.367 ± 0.125	0.381 ± 0.145	.3801
Coma-like (Z_3^{-1} and Z_5^{-1})			
Ocular	0.272 ± 0.158	0.286 ± 0.186	.4215
Corneal	0.619 ± 0.218	0.648 ± 0.366	.2979

*Statistically significant.

mately four times compared to the spherical IOL). The ocular spherical aberration found in eyes implanted with the AcrySof IQ IOL was 0.114 ± 0.147 μm for a 6-mm pupil. The AcrySof IQ IOL spherical aberration is -0.20 μm for a 6-mm pupil (data on file, Alcon Laboratories Inc, Ft Worth, Tex), which combined with the corneal spherical aberration found in our study (0.367 ± 0.125 μm) produces an ocular spherical aberration of approximately 0.1 μm .

Barbero et al⁹ described the sources of aberrations in patients implanted with spherical IOLs. The theoretical advantage offered by aspheric IOLs is to compensate for the spherical aberration of the cornea and to reduce the ocular spherical aberration. Consequently, it is expected to improve the MTF of the whole eye. Marcos et al¹³ pointed out that aspheric IOLs show better in-focus performance than spherical IOLs. However, these authors concluded that best-corrected eyes with spherical IOLs should perform better in near tasks than best-corrected eyes with aspheric IOLs due to differences in depth-of-field between IOLs. Because of this, it is better if spherical aberration is not fully compensated, as a small amount allows for more tolerance of spherical refractive errors. Some moderate residual spherical aberration may benefit those eyes implanted with aspheric IOLs, improving their depth-of-field and consequently the tolerance of a residual ametropia and the need for spectacles for near visual tasks. Our results show that patients with aspheric IOLs have approximately 0.1 μm of spherical aberration. However, we did not evaluate near visual acuity, which would be interest-

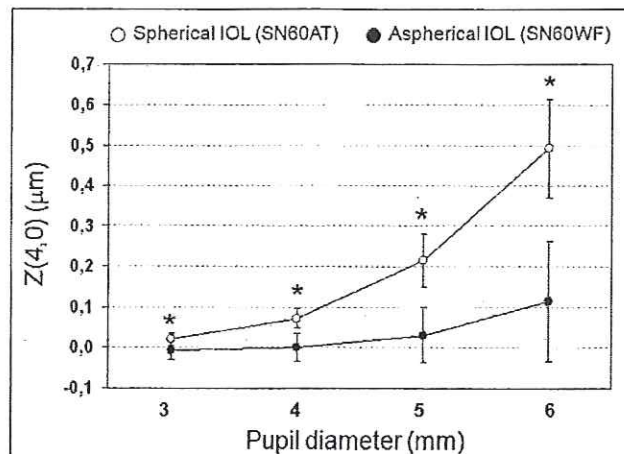


Figure 2. Ocular spherical aberration coefficient (Z_4^0 , μm) for the AcrySof Natural IQ and AcrySof Natural IOL groups as a function of the pupil diameter (mm). The asterisk indicates statistically significant differences between groups.

ing to determine the impact of some residual spherical aberration on visual quality.

Other aspheric IOLs, such as the AMO Tecnis Z9000 (Advanced Medical Optics, Santa Ana, Calif), fully compensate for the total amount of ocular spherical aberration, which improves the final optical quality of the eye.¹³⁻¹⁵ However, some discrepancies exist regarding the visual improvement after this aspheric IOL implantation. Mester et al⁸ reported high and low contrast visual acuity and photopic and mesopic contrast sensitivity results for the AMO Tecnis Z9000, showing a significant improvement in contrast sensitivity and low contrast visual acuity but high contrast visual acuity was unchanged. Bellucci et al¹⁶ concluded that the AMO Tecnis Z9000 IOL yielded better BSCVA and distance contrast sensitivity than the Alcon AcrySof SA60AT. Contrary to these results, Muñoz et al¹⁵ showed no statistically significant differences between the AMO Tecnis Z9000 and two spherical models (AMO AR40e and Ioltech Stabibag IOLs [Zeiss Meditec, Jena, Germany]) in photopic and mesopic contrast sensitivity. Packer et al⁹ found a statistically significant improvement in contrast sensitivity in patients implanted with the AMO Tecnis Z9000 IOL compared to patients with the AMO AR40e IOL at medium-high spatial frequencies under photopic conditions and low spatial frequencies under mesopic conditions. Kershner¹⁰ found better contrast sensitivity in eyes implanted with the AMO Tecnis Z9000 compared to eyes with the Alcon AcrySof SA60 and the STAAR Surgical AA4207VF IOL (STAAR Surgical, Monrovia, Calif) at low spatial frequencies under photopic conditions without glare and no differences at any spatial frequencies under photopic conditions with glare. No significant differences were reported in

contrast sensitivity at low spatial frequencies under mesopic conditions with and without glare. As Muñoz et al¹⁵ reported, the sensitivity of the contrast sensitivity tests used, the differences in the IOL material, and the balance between monochromatic and chromatic aberrations correction may overcome an improvement in visual quality after spherical aberration reduction. Franchini¹⁷ reported aspheric IOLs resolved the spherical aberration problem, but the longitudinal chromatic aberration remained. A new design recently developed solves both problems.¹⁸ However, IOL centration and tilt, inter-subject variability of the corneal spherical aberration, and different negative values of spherical aberration of the aspheric IOL may result in different visual outcomes.

In relation to the visual results found in our study, 100% of patients achieved BSCVA of 20/25 or better in both groups. No statistically significant differences in BSCVA were found between IOLs ($P=.15$). However, the percentage of patients who achieved BSCVA of 20/20 or better was 85% in the AcrySof IQ IOL group and 60% in the AcrySof Natural IOL group. High contrast visual acuity measurement under photopic conditions does not evaluate fully the visual quality of these patients and the role of spherical aberration for large pupil diameters. Although the visual quality of patients under dim conditions was not evaluated, the ocular spherical aberration for different pupil diameters was calculated. This illustrates the role of the aspheric profile of the IOL on the ocular spherical aberration. Figure 2 shows the ocular spherical aberration coefficient for the AcrySof IQ and AcrySof Natural IOL groups as a function of the pupil diameter. Spherical aberration increased significantly with pupil diameter only for the spherical IOL group ($P<.001$). For the AcrySof Natural IOL, the spherical aberration changed from $\sim 0.02 \mu\text{m}$ at 3-mm pupil to $\sim 0.5 \mu\text{m}$ at 6-mm pupil. For the AcrySof IQ IOL, the spherical aberration changed from $\sim -0.01 \mu\text{m}$ at 3-mm pupil to $\sim 0.1 \mu\text{m}$ at 6-mm pupil. Differences between groups were statistically significant at all pupil diameters ($P<.0001$). Kasper et al¹¹ also found that fourth order RMS and Z_4^0 for eyes implanted with the AMO Tecnis Z9000 IOL were significantly lower than those implanted with the AMO AR40e IOL at various pupil diameters (3.0, 3.5, 4.0, 5.0, and 6.0 mm). Z_4^0 for eyes implanted with the AMO Tecnis Z9000 IOL changed from $0.006 \mu\text{m}$ at 3-mm pupil to $0.089 \mu\text{m}$ at 6-mm pupil.¹¹ However, total higher order aberrations RMS of the AMO Tecnis Z9000 IOL was significantly lower than the AMO AR40e IOL only at 6-mm pupil diameter. Differences in terms of residual spherical aberration between both aspheric IOLs come from the spherical aberration of the IOL itself:

$-0.20 \mu\text{m}$ for the AcrySof IQ IOL and $-0.27 \mu\text{m}$ for the AMO Tecnis Z9000 IOL at 6-mm pupil. As suggested, spherical aberration and contrast sensitivity measurements under low illumination conditions would show the role of the spherical aberration reduction in the visual performance of these patients. Differences between aspheric and spherical IOLs are more evident for large pupil diameters (see Fig 2); therefore, differences in visual acuity between both IOLs under dim conditions are expected. However, it remains questionable, as Kasper et al¹¹ suggested, whether differences in spherical aberration (greater for large pupil diameters) have clinical relevance for patients with small mesopic pupil diameters (ie, older patients). This should be addressed in future studies.

Considering our results in terms of optical quality, eyes implanted with the AcrySof Natural IQ IOL showed a significant reduction in spherical aberration at all pupil diameters. Future studies should consider distance and near vision examinations under low lighting conditions to assess the role of the spherical aberration reduction on the visual performance of patients implanted with this IOL.

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