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Ocular wavefront analysis and contrast sensitivity in eyes implanted with AcrySof IQ or AcrySof Natural intraocular lenses

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ABSTRACT.
Purpose: **This study aimed to compare ocular wavefront aberrations for pupil diameters of 4 mm and 6 mm, and contrast sensitivity, in eyes with AcrySof IQ and AcrySof Natural intraocular lenses (IOLs).**
Methods: **Sixty eyes of 60 patients were enrolled in this prospective randomized study. After phacoemulsification the eyes received either AcrySof IQ SN60WF or AcrySof Natural SN60AT IOLs. One month after surgery, all patients underwent complete ophthalmological examination including corneal topography, wavefront analysis for pupil diameters of 4 mm and 6 mm, and contrast sensitivity measurements with the CSV 1000E instrument under photopic and mesopic conditions with and without glare.**
Results: **There was no statistically significant difference between groups in age, sex or other preoperative ocular characteristics ($p > 0.05$). Patients with AcrySof IQ IOLs had higher contrast sensitivity at 6 c.p.d. under photopic conditions, at 6 c.p.d. and 18 c.p.d. under mesopic conditions, and at 6 c.p.d., 12 c.p.d. and 18 c.p.d. under mesopic conditions with glare ($p < 0.05$). Corneal spherical aberration was 0.273 ± 0.074 μm in the AcrySof Natural group and 0.294 ± 0.086 μm in the AcrySof IQ group ($p = 0489$). Ocular spherical aberration was 0.362 ± 0.141 μm and 0.069 ± 0.043 μm ($p < 0.001$) for 6-mm diameter pupils and 0.143 ± 0.091 μm and 0.017 ± 0.016 μm ($p < 0.001$) for 4-mm diameter pupils, with AcrySof Natural and AcrySof IQ IOLs, respectively. There were no significant differences in other higher-order aberrations between the groups ($p > 0.05$).**
Conclusions: **Aspherical AcrySof IQ IOLs significantly reduced spherical aberration for pupil diameters of both 4 mm and 6 mm and also improved contrast sensitivity more than spherical AcrySof Natural IOLs, especially in mesopic conditions.**

Key words: constant sensitivity – intraocular lens – spherical aberration – wavefront analysis

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Introduction

In addition to postoperative visual acuity, modern cataract surgery attempts to improve the quality of visual function in terms of facilitating better night vision or higher contrast sensitivity (CS). Optical quality may be evaluated objectively with wavefront analysis and subjectively with CS measurement. Optical errors of the visual pathway, called higher-order aberrations (HOAs), are responsible for symptoms such as glare, halos, ghost images, reflection and trouble with driving at night. These monochromatic aberrations are defects of vision represented by third- or higher-order polynomials in the Zernike expansion (Thibos et al. 2002). In the past few years, technical advances in ophthalmology have enabled wavefront analysis to quantify HOAs in an optical system that defines the quality of vision (Carvalho 2005; Wang et al. 2005; de Castro et al. 2007). Recently, CS and contrast acuity measurements have also emerged as additional tools providing information about the quality of vision. Higher positive spherical aberration may worsen CS (McLellan et al. 2001). It has been shown that aspherical intraocular lenses (IOLs) induce less loss of CS than spherical IOLs at all spatial frequencies and in photopic and mesopic conditions

(Kershner 2003; Mester et al. 2003; Packer et al. 2004). Higher CS has been seen after implantation of aspherical IOLs than conventional spherical IOLs (Kershner 2003; Mester et al. 2003; Rocha et al. 2006; Denoyer et al. 2007).

Conventional spherical IOLs can worsen image quality by increasing the spherical aberration of the optical system (Mester et al. 2003; Kasper et al. 2006a; Munoz et al. 2006; Rocha et al. 2006; Bellucci et al. 2007). To improve the quality of visual function, new IOLs with an aspherical surface design were developed. Aspherical IOLs can optimize image quality by limiting the diffraction of rays. They have negative spherical aberration and improve visual function by reducing the positive spherical aberration of the corneal surface (Mester et al. 2003; Kasper et al. 2006a; Munoz et al. 2006; Rocha et al. 2006; Bellucci et al. 2007). Aspherical IOLs have been reported to provide better optical quality and lower aberrations than the natural ageing lens because the spherical aberration of the crystalline lens becomes positive with ageing (Holladay et al. 2002).

We determined to compare ocular wavefront aberrations for virtual pupil diameters of 4 mm and 6 mm, and CS measurements, in eyes implanted with aspherical AcrySof IQ and spherical AcrySof Natural IOLs.

Materials and Methods

In this prospective randomized study, we compared the influence of the aspherical AcrySof IQ SN60WF IOL (Alcon Laboratories, Fort Worth, TX, USA) and the spherical AcrySof Natural SN60AT IOL (Alcon Laboratories) on total aberrations and HOAs for virtual pupil diameters of 4 mm (photopic vision) and 6 mm (scotopic vision), and CS, 1 month after cataract surgery.

All patients enrolled in this study agreed to participate, were confirmed as meeting the inclusion criteria and signed informed consent before any procedures were performed. The study was approved by the ethics committee at our hospital and was performed in accordance with the ethical principles described in the Declaration of Helsinki.

Patients were examined before the operations and at 1, 7 and 30 days after surgery. Complete ophthalmological examination including best spectacle-corrected visual acuity (BSCVA), biomicroscopy, applanation tonometry, fundus examination, corneal topography, wavefront analysis and CS were performed. Data for the study were collected during the last postoperative visit. Inclusion criteria were: cataract; corneal astigmatism < 2.0 D; axial length of 22.0–25.0 mm; IOL power between $+ 19.0$ D and $+ 25.0$ D; postoperative absence of posterior capsule opacification, and postoperative BSCVA $\geq 20/25$. Exclusion criteria were: any previous eye surgery; any eye disease such as corneal opacities or irregularity; keratoconus; uveitis; exfoliation syndrome; dry eye; amblyopia; anisometropia; retinal abnormalities and glaucoma; surgical complications; decentration > 0.5 mm; IOL tilt and any systemic disease such as diabetes mellitus. Eyes with intraoperative complications were also excluded.

All patients received a standard dilation regimen of cyclopentolate hydrochloride 1% (Sikloplejin), phenylephrine HCl (Mydfrin 2.5%) and ketorolac tromethamine 0.5% (Acular), 30 mins before the operations. The operations were performed under local anaesthesia with a mixture of lidocaine HCl + adrenaline (Jetokain) and bupivacaine hydrochlorur (Marcaine 0.5%). The surgeries were performed using a standard phacoemulsification technique. Following side-port and clear corneal 3.0-mm incisions, continuous curvilinear capsulorhexis with an approximate diameter of 5.5 mm was performed under sodium hyaluronate 2% (Cohaerens®; LCA Pharmaceutical, Chartres, France). After hydrodissection, phacoemulsification was performed using the stop-and-chop phacoemulsification technique with an Infiniti phacoemulsification unit (Alcon Laboratories). In all cases, a 0.9-mm flared, 30-degree, ABS Kelman microtip was used. The cortex was removed with bimanual infusion/aspiration cannulas. The IOL was implanted in the capsular bag by the injection method through a 3.0-mm incision with a Monarch II B cartridge (Alcon Laboratories). The ophthalmic viscosurgical device was removed from the anterior chamber carefully until no viscoelastic material was visible and the procedure was completed after closure of the incisions by stromal hydration.

Contrast sensitivity testing was performed using the CSV 1000E instrument (Vector Vision, Greenville, OH, USA) by an examiner who was unaware of the type of IOL implanted. Eyes were best corrected during this measurement. The test has a printed chart using sine-wave gratings to measure spatial frequencies of 3, 6, 12 and 18 cycles/degree (c.p.d.). All measurements were performed under photopic (85 c.d./m^2) and mesopic (2.7 c.d./m^2) conditions, with and without glare. For mesopic measurements, a neutral density filter was worn and CS was measured in a dark room. The neutral density filter (1.5 log units) provides a testing luminance level of 2.7 c.d./m^2. The combination of contrast and glare test was performed with a halogen glare source positioned at the sides of the console. For statistical analysis, the table showing the CS scores transformed into log values for the CSV 1000E was used.

Corneal topographic analysis and calculation of the aberration values for the ocular surface (corneal aberration) was performed using the Placido disk-based Keratron Scout Corneal Analyser (Optikon 2000 SPA, Rome, Italy). Ocular wavefront analysis was performed with ORK Wavefront Analyser (SCHWIND Eye-Tech-Solutions GmbH & Co. KG, Kleinostheim, Germany). Pupils were dilated with tropicamide 1% (Tropamid) before the procedure. At least 30 mins later, when the pupils were adequately dilated, measurements were performed. A high-resolution Hartmann–Shack sensor was used for the analysis of wavefront aberration values for the entire eye (ocular aberration). The wavefront maps were analysed using 4-mm and 6-mm virtual pupil diameters and up to the sixth order of Zernike coefficients. Zernike polynomial values Z_2^0 (defocus), $Z_2^{\pm 2}$ (astigmatism), $Z_3^{\pm 1}$ (coma), $Z_3^{\pm 3}$ (trefoil), Z_4^0 (spherical aberration), $Z_4^{\pm 2}$ (secondary astigmatism), $Z_4^{\pm 4}$ (quatrefoil), $Z_5^{\pm 1}$ (secondary coma), $Z_5^{\pm 3}$ (secondary trefoil), $Z_5^{\pm 5}$ (pentafoil), Z_6^0 (secondary spherical), $Z_6^{\pm 2}$ (sixth order astigmatism), $Z_6^{\pm 4}$ (sixth order quatrefoil), $Z_6^{\pm 6}$ (hexafoil) and root mean square (RMS) values for total aberrations and HOAs (RMS value of third to sixth Zernike modes) were calculated for 4-mm and 6-mm pupil diameters.

Statistical analysis was performed using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA). To compare the parameters between two groups, independent-samples *t*-test was used. Statistical analysis of between-group differences in sex and laterality of eyes were performed using the chi-square test. The significance level was set at 5% and a two-way analysis was used for all tests.

Results

Sixty eyes of 60 patients were enrolled in this study. The AcrySof IQ IOL was implanted in 30 eyes and the AcrySof Natural IOL in the other 30 eyes. There was no statistically significant difference between groups in age, sex or other characteristics ($p > 0.05$) (Table 1). No eye had intraoperative or postoperative complications.

Table 2 shows the CS values measured for the aspherical and spherical lenses. Patients with the AcrySof IQ IOL had statistically significant higher CS at 6 c.p.d. under photopic conditions, at 6 c.p.d. and 18 c.p.d. under mesopic conditions, and at 6 c.p.d., 12 c.p.d. and 18 c.p.d. under mesopic conditions with glare ($p < 0.05$).

Corneal topographic analyses were similar and there was no statistically significant difference between the groups according to the corneal parameters measured (Table 1). The corneal spherical aberration was 0.273 ± 0.074 μm in the AcrySof Natural group and 0.294 ± 0.086 μm in the AcrySof IQ group ($p = 0.489$).

Figure 1 shows the ocular aberration values of Zernike expansion for a 6-mm virtual pupil diameter. The spherical aberration (0.362 ± 0.141 μm, 0.069 ± 0.043 μm; $p < 0.001$), mean total HOA (0.636 ± 0.247 μm, 0.259 ± 0.144 μm; $p = 0.002$) and mean RMS coefficient for total ocular aberration (1.961 ± 0.765 μm, 0.956 ± 0.512 μm; $p < 0.001$) were significantly higher in the AcrySof Natural IOL group than in the AcrySof IQ IOL group, respectively. There were no significant differences between the groups in other HOAs ($p > 0.05$) (Fig. 1).

For the 4-mm virtual pupil diameter, the spherical aberration (0.143 ± 0.091 μm, 0.017 ± 0.016 μm; $p < 0.001$) and RMS wavefront error for total ocular aberration (1.113 ± 0.541 μm, 0.751 ± 0.312 μm; $p = 0.001$) were significantly higher in the AcrySof Natural IOL group than the AcrySof IQ IOL group, respectively. There were no significant differences between the groups in other HOAs ($p > 0.05$) (Fig. 2).

Table 1. Characteristics of patients.

Characteristic	AcrySof IQ	AcrySof Natural	p-value
Patients/eyes, *n*	30/30	30/30	
Sex, men/women	17/13	15/15	0.605
Mean age, years	65.2 ± 9.4	67.2 ± 8.6	0.401
Eye, right/left	14/16	17/13	0.438
Keratometry, D	44.5 ± 1.6	44.2 ± 1.6	0.390
Corneal astigmatism, D	0.6 ± 0.4	0.7 ± 0.4	0.273
Axial length, mm	23.4 ± 0.9	23.2 ± 1.1	0.547
Intraocular lens power, D	22.0 ± 1.7	22.3 ± 2.1	0.570

Table 2. Postoperative contrast sensitivity values measured for aspherical (AcrySof IQ) and spherical (AcrySof Natural) intraocular lenses.

	Contrast sensitivity (log units)		
	AcrySof IQ	AcrySof Natural	p-value
Photopic (c.p.d.)			
3	1.53 ± 0.20	1.49 ± 0.22	0.445
6	1.80 ± 0.22	1.65 ± 0.21	0.010
12	1.43 ± 0.21	1.31 ± 0.32	0.101
18	1.08 ± 0.29	0.97 ± 0.32	0.168
Mesopic (c.p.d.)			
3	1.44 ± 0.17	1.34 ± 0.35	0.154
6	1.65 ± 0.31	1.45 ± 0.37	0.027
12	1.30 ± 0.31	1.19 ± 0.37	0.192
18	1.02 ± 0.28	0.82 ± 0.37	0.025
Mesopic with glare (c.p.d.)			
3	1.29 ± 0.21	1.22 ± 0.35	0.320
6	1.52 ± 0.29	1.33 ± 0.31	0.025
12	1.29 ± 0.35	1.04 ± 0.35	0.009
18	0.89 ± 0.31	0.69 ± 0.37	0.030

c.p.d. = cycles per degree.

Discussion

Higher-order aberrations are defects of vision represented by third or higher-order polynomials in the Zernike expansion. These aberrations affect vision, but, unlike lower-order aberrations (sphere and cylinder), they cannot be corrected by spectacle lenses. In normal eyes, HOAs are not seen frequently and are dominated by spherical aberrations in which the image of a point is usually a bright dot surrounded by a halo of light.

Today, cataract surgery can reduce lower-order aberrations, but it is not intended to reduce HOAs successfully. Conventional spherical IOLs decrease image quality by introducing positive spherical aberration. Because of their negative spherical aberration, aspherical IOLs are able to compensate for the positive spherical aberration of the cornea, which is the only correctable HOA of the Zernike pyramid. In this study, we compared corneal and ocular aberrations, and CS, with spherical AcrySof Natural and aspherical AcrySof IQ IOLs implanted after phacoemulsification. The AcrySof IQ IOL includes blue-light filter properties associated with a posterior aspherical design developed to reduce spherical aberration.

Marcos et al. (2007) found that small-incision cataract surgery in patients with two types of aspherical IOLs induced consistent changes in corneal astigmatism and tetrafoil, but did not induce spherical aberration or

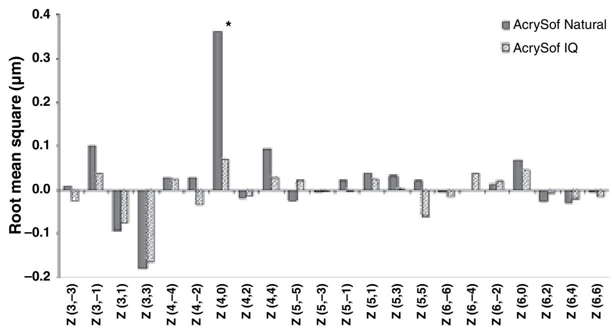

Fig. 1. Mean ocular root mean square values of Zernike modes for 6-mm virtual pupil diameter. * $p < 0.001$; spherical aberration significantly lower in the AcrySof IQ group than the AcrySof Natural group.

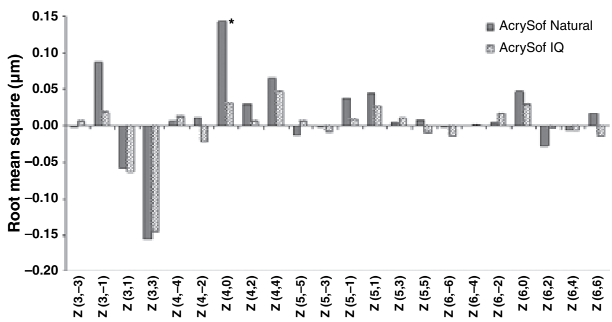

Fig. 2. Mean ocular root mean square values of Zernike modes for 4-mm virtual pupil diameter. * $p < 0.001$; spherical aberration significantly lower in the AcrySof IQ group than the AcrySof Natural group.

coma terms. These findings suggest that aspherical IOLs can work under the assumption that spherical aberration remains unchanged after small-incision cataract surgery.

Other than higher-order astigmatism, the only HOA addressed by today's IOLs is spherical aberration because this is the only aberration which is rotationally symmetrical and which does not require specific rotation of the IOL inside the eye. Spherical IOLs add to the positive corneal spherical aberration and have little effect on other aberrations (Guirao et al. 2002). Many studies have found a reduction in spherical aberration after aspherical IOL implantation (Mester et al. 2003; Kasper et al. 2006a, 2006b; Munoz et al. 2006; Rocha et al. 2006; Bellucci et al. 2007). Although aspherical IOLs are used widely, their effect on the other ocular aberrations is not yet clear. Kasper et al. (2006a) found that the aspherical Tecnis IOL reduced Z_4^0 and fourth-order RMS significantly for pupil diameters of 3–6 mm, whereas total HOA RMS was only significantly reduced for a pupil diameter of 6 mm. Clear differences between the IOLs were found only for pupils with diameters of 5 mm and 6 mm, with lower values in the aspherical group.

In this study, we found that the spherical aberrations with AcrySof IQ and AcrySof Natural IOLs for a 4-mm pupil diameter were 0.017 μm and 0.143 μm, respectively, and for a 6-mm pupil diameter were 0.069 μm and 0.362 μm, respectively. Spherical aberration was statistically significantly lower in eyes with the aspherical IOL for both pupil diameters. Mean total HOA and mean RMS for total ocular aberration were also lower with the AcrySof IQ IOL than the AcrySof Natural IOL for a pupil diameter of 6 mm, whereas only total RMS wavefront error was lower for a pupil diameter of 4 mm. There were no significant differences in other HOAs between the two groups.

Coma aberration is the second most important HOA; it arises from the imperfect centration and physical tilt of different refractive interfaces (Applegate et al. 2000). Munoz et al. (2006) found that coma aberration was less with the Tecnis Z9000 IOL than with the Stabibag IOL and concluded that this finding may reveal interaction between aberrations (i.e. improvement in one [spherical aberration] might also improve another [coma]). Dietze & Cox (2005) stated that aspherical IOLs could produce more coma aberration when decentred or misaligned. Bellucci et al. (2007) reported that induced coma was higher with the Tecnis IOL and concluded that physiological IOL decentration after correct in-the-bag implantation did not negate the advantages of asphericity. The advantages of these lenses could be reduced by decentration, by the small pupil and by the reduced transparency of the optical media. However, the improvement in optical quality has been confirmed by studies *in vivo*, although the reduction in the total eye wavefront error appeared to vary widely (Bellucci & Morselli 2007). Guirao et al. (2004) stated that small-incision surgery did not degrade the optical quality of the corneal surface, although it introduced changes in aberrations such as coma and trefoil. In this study, the RMS values of trefoil and coma were second- and third-highest values after spherical aberration and there was no statistically significant difference in aberrations between the two IOLs for pupil diameters of either 4 mm or 6 mm. As the IOLs were all properly centred in the eyes in our study, this finding suggests that well-centred aspherical IOLs will not cause coma. We have also seen that trefoil aberration, which is considered to be induced by clear corneal incisions, increased in pupil diameters of 6 mm. As we evaluated the patients 1 month postoperatively, we think that new studies should be performed to evaluate how capsulorhexis shrinkage and the healing process after clear corneal incision affect HOAs postoperatively in the long-term.

Contrast sensitivity in pseudophakic eyes may be affected by a variety of factors such as pupil size, illumination conditions, presence of glare and ocular aberrations. Implantation of an aspherical IOL should restore the spherical aberration to the level of young phakic eyes, which would lead to higher CS (Wang et al. 2005; Rocha et al. 2006).

Several clinical studies show higher CS after implantation of aspherical IOLs than standard spherical IOLs (Mester et al. 2003; Kasper et al. 2006b; Rocha et al. 2006; Denoyer et al. 2007). Pandita et al. (2007) found that eyes with the AcrySof IQ IOL had higher CS than eyes with AcrySof SA60AT or AcrySof Natural IOLs at all spatial frequencies during mesopic testing with and without glare and concluded that the mechanism for improvement in contrast with the AcrySof IQ could be attributed to the modified posterior surface of the single-piece lens, which compensates for the spherical aberration that can be induced from the cornea and lens. Mester et al. (2003) reported that reduced spherical aberration resulted in a significant improvement in CS and proposed that IOLs with an aberration profile would improve vision under mesopic conditions. Rocha et al. (2006) stated that CS values in photopic conditions were similar between the IOLs but the AcrySof IQ showed better results in 3 c.p.d. spatial frequency in mesopic conditions and concluded that its asphericity was the factor that provided better CS in mesopic conditions. Denoyer et al. (2007) reported that implantation of an aspherical IOL with a negative spherical aberration resulted in reduced ocular spherical aberration and improved mesopic CS and led to better subjective quality of vision.

In this study, under photopic conditions mean CS with the AcrySof IQ IOL was higher only at a spatial frequency of 6 c.p.d. Under mesopic conditions mean CS was higher at 6 c.p.d. and 18 c.p.d. without glare and at spatial frequencies of 6 c.p.d., 12 c.p.d. and 18 c.p.d. with glare. Both the AcrySof IQ and AcrySof Natural are yellow-tinted IOLs which have blue-light filtering chromophore intended to attenuate the blue light to improve CS. As both IOLs have yellow-tinted acrylic material and only the AcrySof IQ has an aspherical design, the mechanism for improvement in CS with the AcrySof IQ must be attributed to the aspherical design of the IOL.

In conclusion, the aspherical AcrySof IQ IOL significantly reduced spherical aberration for pupil diameters of both 4 mm and 6 mm. The aspherical IOL also improved CS more than the spherical IOL, especially in mesopic conditions. Further studies are required to evaluate the longterm postoperative affect on HOAs of capsulorhexis shrinkage and the healing process of clear corneal incision.

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