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A comparison of higher order aberrations in eyes implanted with AcrySof IQ SN60WF and AcrySof SN60AT intraocular lenses

S.T. AWWAD, J.D. LEHMANN, J.P. McCULLEY, R.W. BOWMAN

Department of Ophthalmology, University of Texas Southwestern Medical Center at Dallas, Dallas - USA

PURPOSE. *To evaluate the efficacy of AcrySof SN60WF aspheric intraocular lens (IOL) in decreasing spherical aberration and total higher order aberrations (HOAs) after cataract surgery compared to the spherical SN60AT lens.*
METHODS. *Wavefront analysis was conducted on 28 eyes of 28 patients that underwent uncomplicated phacoemulsification with implantation of either SN60WF (15 eyes) or SN60AT lenses (13 eyes). Eyes with a history of uveitis, retinal diseases, and previous surgery were excluded.*
RESULTS. *SN60WF eyes had less mean absolute spherical aberration than SN60AT eyes both at 4 mm (0.04±0.03 vs 0.11±0.03 RMS, p<0.0001) and 6 mm pupils (0.09±0.04 vs 0.43±0.12 RMS, p<0.0001). Mean total HOAs was lower in the SN60WF group at 6 mm pupils (0.44±0.14 vs 0.56±0.13 RMS, p=0.0274), while no difference was seen at 4 mm pupils (0.20±0.10 vs 0.25±0.08 RMS, p=0.160). There were no clinically significant differences between the SN60WF and SN60AT IOLs both at 4 and 6 mm pupils in terms of coma (0.16±0.07 vs 0.18±0.09 RMS, p=0.514 and 0.25±0.12 vs 0.23±0.12 RMS, p=0.664) and trefoil (0.14±0.09 vs 0.10±0.05 RMS, p=0.167 and 0.28±0.12 vs 0.23±0.07 RMS, p=0.199). There were no differences between groups in mean age, axial length, postoperative spherical equivalent, IOL power, or corneal curvature.*
CONCLUSIONS. *An aspheric posterior optic IOL design with thinner center effectively reduces the positive ocular spherical aberration observed in the pseudophakic and elderly eyes, especially at larger pupillary diameters (6 mm), with no notable increase in coma. However, reduction in total ocular HOAs was only significant at 6 mm pupils. (Eur J Ophthalmol 2007; 17: 320-6)*

KEY WORDS. *Intraocular lens, Spherical aberration, Aspheric IOL, Higher order aberrations*

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INTRODUCTION

Optical higher order aberrations (HOAs) were measured for the first time in the human eye by Liang et al in 1993 (1), and since then, they have been the subject of numerous studies which revolutionized the field of refractive surgery. Ocular HOA, mainly spherical aberration and coma, have been shown to have a negative effect on contrast sensitivity and visual function, and have been associated with optical side effects like glare and haloes (2-9).
The crystalline lens and the cornea of the human eye play an important role in determining the total ocular spherical aberration. The cornea produces positive

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spherical aberration. An aspherical prolate cornea with flatter curves peripherally yields less positive spherical aberration than a hypothetical spherical cornea due to weaker light refraction peripherally. The crystalline lens, especially when young, has a higher refractive index in the center compared to the periphery, producing negative spherical aberration. The latter partially compensates for the positive spherical aberration produced by the cornea (10, 11). With time, the corneal spherical aberration changes little, while the spherical aberration of the crystalline lens becomes less negative, and after age 40, becomes positive (12). This is believed to be due to lenticular structural changes such as hardening of the nucleus (13), changes in internal refractive index gradient (14), and the equivalent refractive index (15), and changes in lens shape (15). This leads to a progressive increase in ocular spherical aberration as well as total HOAs (16). These changes result in a dramatic increase in ocular total HOAs and spherical aberration seen in humans between 20 and 70 years of age (11).

After cataract surgery, implantation of spherical intraocular lenses (IOLs) produces additional positive spherical aberration, which works against restoring the initial lower spherical aberration balance of the youthful eye. Newer generations of IOLs have recently been designed with either a prolate anterior optic surface (17) or an aspheric thinner posterior optic surface center, to produce negative spherical aberration to compensate for the average positive spherical aberration of the cornea. In this study, we compared the ocular HOAs of eyes implanted with the aspheric IOL AcrySof IQ SN60WF to those of the conventional spherical biconvex AcrySof SN60AT in order to evaluate the clinical impact of the aspheric IOL technology.

MATERIALS AND METHODS

Twenty-eight eyes of 28 consecutive patients who underwent cataract extraction through uncomplicated phacoemulsification and implantation of either AcrySof SN60AT or AcrySof IQ SN60WF IOL were enrolled between December 2004 and April 2005. Inclusion criteria included axial length measurements between 22 mm and 28 mm and a 3-month postoperative best-spectacle corrected visual acuity of 20/20 or better. Exclusion criteria comprised intraoperative complications, IOL decentration by more than 0.5 mm, any vitreoretinal or corneal disease, or a previous history of ocular surgery, uveitis, trauma, or systemic disease affecting vision. The two types of IOLs share the same physical quality: both are ultraviolet and blue light filtering single-piece IOLs made of hydrophobic acrylic material with a refractive index of 1.55 and a 6.0 mm square-edged biconvex optic, and a 13.0 mm overall length (Tab. I). The AcrySof IQ SN60WF has in addition an aspheric posterior optic design with a thinner posterior center, resulting in negative spherical aberration. The study was performed with the approval of the University of Texas Southwestern Medical Center Institutional Review Board and in accordance with the Declaration of Helsinki guidelines for human research and the Health Insurance Portability and Accountability Act (HIPAA). All the procedures were performed at Zale Lipshy University Hospital, University of Texas Southwestern Medical Center at Dallas.

Phacoemulsification was performed by R.W.B. and J.D.L., and all patients received either topical anesthesia or peribulbar injection before surgery. A 3.0-mm self-sealing corneal incision was created along the steep-

TABLE I - CHARACTERISTICS OF THE ACRYSOF IQ SN60WF AND THE ACRYSOF NATURAL SN60AT INTRAOCULAR LENSES (IOL)

Characteristics	AcrySof IQ SN60WF	AcrySof SN60AT
Optic surface	Aspheric posterior optic	Equally biconvex
Optic design	Square edge	Square edge
Optic diameter	6.0 mm	6.0 mm
Optic material	Hydrophobic acrylic	Hydrophobic acrylic
Refractive index	1.55	1.55
Loop design	One-piece IOL	One-piece IOL
Loop material	Hydrophobic acrylic	Hydrophobic acrylic
Overall diameter	13 mm	13 mm

est meridian, and a 5-mm continuous curvilinear capsulorrhexis was performed in the anterior capsule. After hydrodissection, the nucleus was emulsified by the stop-and-chop method. Irrigation-aspiration and posterior capsular polishing using a silicone tip cannula followed. The IOL was implanted in the bag using the Monarch II injection system (Alcon Labs, Fort Worth, TX), and was dialed into position. Care was taken to achieve good IOL centration. The corneal wound was not sutured.

Ocular HOAs were measured in every eye at optical zones of 4.0 mm and 6.0 mm, 3 months after phacoemulsification and IOL implantation using the LADARWave aberrometer (Alcon, Inc., Fort Worth, TX). Pupils were induced to constrict and dilate physiologically by controlled room illumination, with an adjustable light intensity source. One drop of phenylephrine 2.5% ophthalmic solution was used when the scotopic pupil did not clear the 6.0 mm optical zone. The HOAs recorded from the LADARWave aberrometer display were spherical aberration (Z4,0), coma (Z3,-1 and Z3,1), trefoil (Z3,-3 and Z3,3), and total HOAs. The data were transferred to an Excel spreadsheet, tabulated, then analyzed using Sigmastat™ software (Jandel Scientific, San Rafael, CA). Statistical comparisons of age, keratometry, axial length, postoperative spherical equivalent, and IOL power were performed using the Student *t*-test (two-tailed distribution). Statistical comparisons of HOAs were performed using the Student *t*-test and the Mann-Whitney *U* test. A p value of less than 0.05 was considered statistically significant.

RESULTS

Cohort characteristics

The demographic data and characteristics of each group are summarized in Table II. There were no statistically significant differences between groups in mean age, axial length, corneal curvature, IOL power, or postoperative spherical equivalent.

Higher order aberration profile

The mean total and individual HOAs for each group at different pupillary diameters (4.0 and 6.0 mm) are summarized in Tables III and IV. Eyes implanted with AcrySof IQ SN60WF IOL had less spherical aberration than eyes implanted with SN60AT IOL, both at pupil diameters of 4.0 mm (–0.04±0.03 vs 0.11±0.03 RMS, p<0.0001) and 6.0 mm (0.09±0.04 vs 0.43±0.12 RMS, p<0.0001). When comparing the mean absolute spherical aberration at 4.0 mm pupil, the AcrySof IQ group still yields a lower mean absolute spherical aberration value than the AcrySof Natural group (0.04±0.03 vs 0.11±0.03 RMS, p=0.0001) (Fig. 1). At pupil diameter of 6.0 mm, eyes implanted with AcrySof IQ SN60WF had less mean total HOAs (0.44±0.14 vs 0.56±0.13 RMS, p=0.0274) than eyes with SN60AT IOL. However, at 4.0 mm pupils, there were no statistically significant differences between the two groups in terms of coma, trefoil, or total HOA RMS (Tab. III).

The mean absolute ocular spherical aberration in-

TABLE II - PATIENT DEMOGRAPHICS AND CHARACTERISTICS

Characteristics	AcrySof IQ SN60WF	AcrySof SN60AT	p value
No. of eyes	15	13	—
No. of patients	15	13	—
Male/female	8/7	6/7	—
Mean age±SD, yr	70±13.17	66.7±11.04	0.623
Axial length±SD, mm (range)	23.54±1.25 (22.30 to 25.95)	23.89±1.17 (22.39 to 25.21)	0.478
Mean preoperative keratometry±SD, D (range)	44.10±1.34 (41.83 to 46.06)	44.22±1.21 (42.62 to 45.12)	0.807
Mean IOL power±SD, D (range)	20.39±2.79 (16.5 to 24.0)	19.77±2.53 (17.0 to +23.5)	0.546
Mean 1-month postoperative SE±SD, D (range)	–0.18±0.41 (0.25 to –0.75)	–0.12±0.36 (0.12 to –0.9)	0.686

SD = Standard deviation; IOL = Intraocular lens; D = Diopter; SE = Spherical equivalent

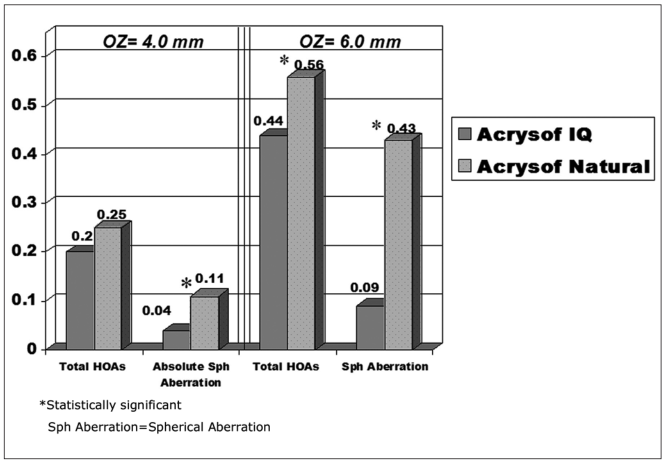

Fig. 1 - *Mean total higher order aberrations (HOAs) and spherical aberrations (Sph Aberration) plotted for both groups as a function of pupil diameter. *Statistically significant.*

creased in both groups as the optical zones were taken from 4.0 mm to 6.0 mm (0.04±0.03 to 0.09±0.04 RMS, p=0.0026 for SN60WF, and 0.11±0.03 to 0.43±0.12 RMS, p<0.0001 for SN60AT). However, the change in spherical aberration with optical zone change was larger in the SN60AT group than the SN60WF group (0.32±0.09 vs 0.13±0.04 RMS, p=0.0001).

DISCUSSION

Aspheric IOLs are designed to simulate the function of the youthful crystalline lens, compensating for the positive spherical aberration of the cornea. Eyes implanted with the aspheric AcrySof IQ SN60WF IOL should therefore have less positive ocular spherical aberration than eyes implanted with the spherical AcrySof SN60AT. Indeed, the mean spherical aberration in the SN60WF eyes was less than the SN60AT eyes at both 4.0 mm and 6.0 mm optical zones. In addition, the mean absolute ocular spherical aberration was lower in the SN60WF eyes as compared to the SN60AT eyes, as the absolute value of the spherical aberration is more meaningful clinically. The average ocular spherical aberration at 6 mm pupils in eyes of patients who are candidates for refractive surgery has been reported by Wang and Koch (18), and was found to be 0.13 RMS, a figure similar to the 0.09 RMS value seen in AcrySof IQ eyes, and much lower than the 0.43 RMS value of the AcrySof SN60AT eyes. It is important to mention that preoperative HOAs were not measured in the current study due to the presence of cataract, which by itself is a major confounding factor in ocular HOA measurements.

TABLE III - MEAN HIGHER ORDER ABERRATIONS (HOA) AT OPTICAL ZONE OF 4.0 MM

Mean HOAs	AcrySof IQ SN60WF	AcrySof SN60AT	p value
Total HOAs±SD, RMS (range)	0.20±0.10 (0.11 to 0.37)	0.25±0.08 (0.15 to 0.35)	0.1604
Spherical aberration±SD, RMS (Range)	-0.04±0.03 (-0.08 to 0.01)	0.11±0.03 (0.07 to 0.16)	<0.0001
Coma±SD, RMS (range)	0.16±0.07 (0.04 to 0.26)	0.18±0.09 (0.09 to 0.27)	0.5145
Trefoil±SD, RMS (range)	0.14±0.09 (0.06 to 0.28)	0.10±0.05 (0.06 to 0.16)	0.1671

SD = Standard deviation; RMS = Root mean square

TABLE IV - MEAN HIGHER ORDER ABERRATIONS (HOA) AT OPTICAL ZONE OF 6.0 MM

Mean HOAs	AcrySof IQ SN60WF	AcrySof SN60AT	p value
Total HOAs±SD, RMS (range)	0.44±0.14 (0.30 to 0.61)	0.56±0.13 (0.34 to 0.66)	0.0274
Spherical aberration±SD, RMS (range)	0.09±0.04 (0.04 to 0.15)	0.43±0.12 (0.19 to 0.58)	<0.0001
Coma±SD, RMS (range)	0.25±0.12 (0.09 to 0.41)	0.23±0.12 (0.12 to 0.40)	0.6637
Trefoil±SD, RMS (range)	0.28±0.12 (0.11 to 0.35)	0.23±0.07 (0.14 to 0.31)	0.1988

SD = Standard deviation; RMS = Root mean square

While there was a modest increase in spherical aberration in the SN60WF group from 4.0 to 6.0 mm optical zone, the increase in the SN60AT group was more dramatic. This suggests that the negative spherical aberration of the aspheric AcrySof IQ lens increases toward the optic periphery. This gradation parallels and compensates for the increasing positive corneal spherical aberration that comes into play as the pupil dilates. A large and fixed IOL negative spherical aberration value would have resulted in a large net negative ocular spherical aberration at smaller optical zones. Clinically, this translates into a large mean absolute ocular spherical aberration at photopic pupil size, potentially decreasing contrast sensitivity and bringing about symptoms like glare and haloes. Other ocular HOAs such as coma and trefoil were not statistically different in the two groups. Piers and associates showed, using adaptive optics, that visual acuity as well as contrast sensitivity improved markedly upon correction of an equivalent amount of ocular spherical aberration seen in pseudophakic eyes with spherical IOLs (19). Also, the change in spherical aberration correlated negatively with the change in area under the log contrast sensitivity function (AULCSF) in post-LASIK eyes (20). Casprini et al have shown that spherical aberration is linked to glare under scotopic conditions in pseudophakic eyes (21). In addition, Chalita et al have shown that spherical aberration correlated with glare and starburst in post-LASIK patients under scotopic conditions (22). Hence, a better spherical aberration profile overall seems to be associated with a better contrast sensitivity and less nighttime symptoms of glare and starbursts. However, contrast sensitivity testing should be performed on eyes implanted with AcrySof IQ and SN60AT IOLs in order to verify the applicability of the latter statement on the aspheric lenses.

Although spherical aberration was statistically significantly less in SN60WF implanted eyes at both pupillary diameters, the spherical aberration lowering effect seems to be more at larger pupil sizes (6.0 mm vs 4.0 mm). Hence, total HOAs were not different between the two groups at 4 mm pupil, confirming previous studies conducted on the aspheric Tecnis and the spherical AR40e IOLs (23). As elderly patients have smaller physiologic pupil sizes than young patients (24), the aspheric AcrySof IQ would possibly benefit the younger pseudophakic population more. Also, the visual benefit would be expected to be much more at mesopic and scotopic conditions than under photopic conditions, mainly because of the larger pupil diameter under mesopic/scotopic states.

At small pupil sizes, ocular spherical aberration is relatively mild, and the modulation transfer function is determined mainly by chromatic aberration and diffraction. Franchini has shown that an aspheric IOL design does not correct for chromatic aberration (25), which is more important in pseudophakic eyes and has more effect due to lack of accommodation (26). In addition, the presence of some degree of spherical aberration, especially under polychromatic conditions, as in the spherical IOL group at 4 mm pupil diameter, imparts some advantage by increasing the depth of focus (25, 27).

It has been shown that tilt and decentration of spherical biconvex IOLs can lead to the induction of coma (28-30). There are also concerns that tilt and decentration of aspheric IOLs can induce HOAs much more than spherical IOLs. A study performed by Altmann and associates using a ray tracing software to simulate the HOA induction upon decentration showed that IOLs with neutral spherical aberration had the least aberration induction with decentration, followed by the spherical and the aspherical IOLs (31). However, Dietze and Cox have shown, using model eyes, that total ocular HOAs induced by aspherical IOL tilt are similar, if not less than those induced by an equal tilt of spherical IOLs (32). However, they showed that aspheric IOL decentration of more than 0.5 mm can induce more aberrations than spherical IOLs. They also showed that a combined aspheric IOL tilt and >0.5 mm decentration can either lead to more or to less induced HOAs than the spherical lenses, depending on the direction of tilt. Making sure that the aspheric IOL decentration does not exceed 0.5 mm is therefore key in achieving optimal visual results over spherical IOLs. In this study, no eye in either group had a decentration of more than 0.5 mm, as judged by slit-lamp examination, and none had a clinically detectable tilt, thus minimizing the effects of such confounding variables. Since the two IOLs share the same physical properties except for the posterior optic shape, the mean amount of subclinical tilt can be assumed to be similar for both IOLs. Consequently, since coma and trefoil were not different in both IOL groups, we can assume that subclinical decentration and tilt in both IOL types had similar effect on ocular coma and HOAs. However, the effect of potential IOL tilt from latent capsular contraction is yet to be studied. Previous reports compared the Tecnis aspheric prolate anterior optic IOL to other conventional IOLs in terms of contrast sensitivity and/or HOA profiles (23, 33-35). Although both studies showed better results in the Tecnis-implanted eyes, the conventional IOLs to which the Tecnis IOL was compared had a different optic material and refractive index, and had a different overall platform design. Those differences are a confounding factor, since they are well known to influence the ocular HOAs, and therefore the contrast sensitivity profile (36). We compared IOLs sharing the same platform design and the same physical characteristics except for the shape of the posterior surface, minimizing confounding factors such as tilt and IOL-specific HOAs.

In summary, the implantation of aspherical AcrySof IQ SN60WF IOL without clinically detectable tilt and decentration provides a better ocular spherical aberration profile than the spherical AcrySof SN60AT IOL, both at 4.0 and 6.0 mm pupil diameters. The total HOA lowering effect, however, is mainly seen at larger pupillary diameters (6.0 mm). Hence, the potential beneficial effect of the aspheric IOL on visual quality seems to be more important at larger pupillary diameters, such as under scotopic and mesopic conditions. In addition, young patients with larger mesopic pupils might fare better, vision-wise, than elderly patients with small mesopic pupils. More importantly, although large spherical aberration values have been linked to poor visual function (19-22), we cannot assume, based solely on the results of this study, that the visual quality of eyes implanted with the aspheric AcrySof IQ IOL is superior to that of the spherical AcrySof SN60AT. The impact of such new generations of IOLs on the quality of vision should be further evaluated by contrast sensitivity testing on large patient samples. The effect of tilt and decentration on the HOA profile has yet to be investigated on larger sample sizes with concomitant use of accurate tilt measuring devices such as Scheimpflug imaging.

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Reprint requests to:
R. Wayne Bowman, MD
Department of Ophthalmology
University of Texas Southwestern Medical Center at Dallas
5323 Harry Hines Blvd.
Dallas, TX 75390-9057 USA
wayne.bowman@utsouthwestern.edu

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