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CLINICAL INVESTIGATION

Wavefront Analysis of Acrylic Spherical and Aspherical Intraocular Lenses

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Abstract

Purpose: To compare higher order wavefront aberrations in eyes implanted with acrylic aspherical intraocular lenses (IOLs) with a modified prolate anterior surface with conventional acrylic spherical IOLs by using the optical path difference method.

Methods: In a nonrandomized parallel cohort investigation, 36 eyes of 31 patients implanted with aspherical IOLs (Tecnis ZA9003) and 37 eyes of 23 age-matched patients implanted with spherical IOLs (SENSOR AR40e) were evaluated with a wavefront analyzer (OPD-Scan II) preoperatively and 1 month after surgery. The higher order aberrations for a 4.0-mm pupil diameter were expanded into Zernike's polynomial expression. Coma aberration, spherical aberration, and total higher order aberrations were evaluated as root mean square values.

Results: Postoperatively, coma and total higher order aberrations of spherical and aspherical IOLs significantly improved in both eyes. Spherical aberration improved in eyes with aspherical IOLs only ($P < 0.01$).

Conclusion: After implantation of acrylic aspherical IOLs, postoperative higher order aberrations were not necessarily lower than after implantation of acrylic spherical IOLs, but compared with levels following implantation of acrylic spherical IOLs, a significant reduction in spherical aberration was achieved. **Jpn J Ophthalmol** 2008;52:250–254 © Japanese Ophthalmological Society 2008

Key Words: aspherical intraocular lense, higher order aberration, optical path difference method, wavefront analysis

Introduction

In patients with developed cataracts, higher order aberrations are enlarged compared with in normal young people, resulting in image defocusing and monocular diplopia or triplopia.[1–3] The enlargement of higher order aberrations is due to the collapse of the complementary relationship between the cornea and crystalline lens present in the young,[4] which is caused by changes in the form and refractive index of the crystalline lens with age.[5] Cataract surgery and the implantation of an intraocular lens (IOL) improve this decreased optical function, after which the optical function of pseudophakic eyes depends on the optical character of the IOL.[6]

A conventional IOL has a positive spherical surface, while an aspheric IOL has a modified prolate anterior surface with a negative spherical aberration, developed to decrease the total amount of ocular spherical aberration after cataract surgery.[7] The advantage of the aspheric IOL from the point of view of higher order aberrations has been clarified with the development of the wavefront analyzer.

In this study, we analyzed and compared higher order aberrations in eyes with acrylic aspherical or spherical IOL implantations by using the optical path difference method.

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Patients and Methods

A nonrandomized parallel cohort investigation of patients requiring either unilateral or bilateral cataract surgery at Yokohama City University Hospital or Yokohama City University Medical Center was conducted. The study population included 37 eyes of 23 patients implanted with acrylic spherical three-piece IOLs (Sensar AR40e, AMO, Santa Ana, CA USA) at Yokohama City University Hospital between June 2003 and February 2004, and 36 eyes of 31 patients implanted with acrylic aspherical three-piece IOLs (Tecnis ZA9003, AMO) at Yokohama City University Medical Center between April 2006 and August 2006. Subject data are shown in Table 1. No statistically significant difference was observed between the two groups. None of the patients had organic diseases beyond refractive anomalies and cataracts, and none had a history of any ocular surgery. Cataract severity ranged from grade 1 to grade 3 according to the Emmery-Little classification. Eyes in which best-corrected visual acuity deteriorated after surgery, compared with that before surgery, or in which the refractive power deviated from the target by more than ±1.5 diopters in spherical equivalent, were excluded. Ethical approval for our study was obtained from the Institutional Review Board of Yokohama City University. The procedures were explained in detail to all patients, and their written consent was obtained.

Intraocular Lenses

The Sensar AR40e and the Tecnis ZA9003 are both three-piece IOLs, and the optics and haptics of both are composed of hydrophobic acrylic material. Both IOLs have the same overall length of 13.0 mm, an optic diameter of 6.0 mm, and a refractive index of 1.47. The Tecnis ZA9003 has a modified prolate anterior surface, while the Sensar AR40e is biconvex with a spherical surface that is not designed to reduce spherical aberrations; therefore, the estimated A-constant of the Tecnis ZA9003 is 119.1, while that of the Sensar AR40e is 118.4.

Table 1. Subject data

	Spherical IOLs	Aspherical IOLs
Number of eyes	37	36
Number of subjects	23	31
Sex (female : male)	20 eyes : 17 eyes	22 eyes : 14 eyes
Age (years)		
mean ± SD	68.7 ± 10.3	73.5 ± 7.2
(range)	(48 to 85)	(52 to 87)
Preoperative refraction (spherical equivalent)		
mean ± SD	−3.75 ± 4.74	−3.24 ± 3.88
(range)	(−12.0 to +4.25)	(−11.5 to +3.00)
Power of implanted IOLs		
mean ± SD	19.8 ± 3.22	20.5 ± 2.80
(range)	(13.0 to 24.5)	(15.0 to 25.0)

IOL, intraocular lens.

Surgical Technique

All patients underwent day surgery performed by a single surgeon (Y.W.). Patients were placed under local anesthesia with epinephrine containing 2% lidocaine, and phacoemulsification was performed using a 3.0-mm superior scleral incision, capsulorhexis, and symmetric implantation of the IOL in the capsular bag with an Emerald injector.

Evaluation

Patients were examined with a wavefront analyzer (OPD-Scan, NIDEK, Gamagori, Japan) preoperatively and 1 month after surgery. This device is used to take measurements by the optical path difference method, which is based on skiascopy, a method to obtain the refractive power by observing the reflected image of the incident light from the ocular fundus. The device detects the reflected light from the cornea with eight phototransistors set conjugate to the cornea. Each phototransistor is stimulated at a different time, owing to the different distances between the collimator of the device and the fundus at each point on the cornea and at the center of the cornea. The device measures the time differences, converts these into the refractive power at 1440 spots on the cornea, and decomposes the wavefront error into a set of Zernike polynomials of up to eighth order for a 6.0-mm pupil. The root mean square (RMS) values for higher order aberration (ΣS_n, $n \geq 3$), spherical-like aberrations ($S_4 + S_6 + S_8$), and coma-like aberrations ($S_3 + S_5 + S_7$) were calculated from the Zernike polynomials for 4.0-mm pupil diameters.

Results

In the spherical IOL group, the mean RMS values for coma-like aberrations, spherical-like aberrations, and total higher order aberrations were respectively 0.373, 0.096, and 0.390 μm preoperatively, and 0.222, 0.069, and 0.237 μm 1 month postoperatively. In the aspherical IOL group, the respective values were 0.368, 0.168, and 0.413 μm preoperatively, and 0.251, 0.088, and 0.278 μm postoperatively. Both groups exhibited a statistically significant improvement in coma-like aberrations and total higher order aberrations postoperatively, while only the aspherical IOL group exhibited a statistically significant improvement in spherical-like aberration (Fig. 1).

We compared the improvement rate of spherical aberrations between the two groups, since there was a large difference in preoperative spherical aberrations between the groups. In the spherical IOL group, 21 of 37 eyes (57%) exhibited improved spherical aberrations at an improvement rate of −1.3 ± 62.5% (mean ± standard deviation). In the aspherical IOL group, 32 of 36 eyes (89%) exhibited improved spherical aberrations at an improvement rate of 41.0 ± 27.3%. There was a statistically significant difference

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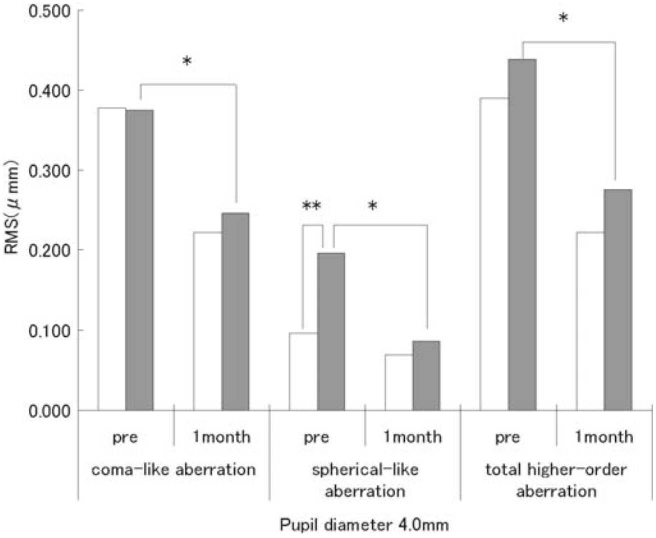

Figure 1. Histogram comparing preoperative values and values 1 month after surgery for coma-like aberration, spherical-like aberration, and higher order aberration (□ AR40e, ▨ ZA9003). *RMS*, root mean square. **P* < 0.01 (Mann-Whitney *U* test); ***P* < 0.01 (Wilcoxon test).

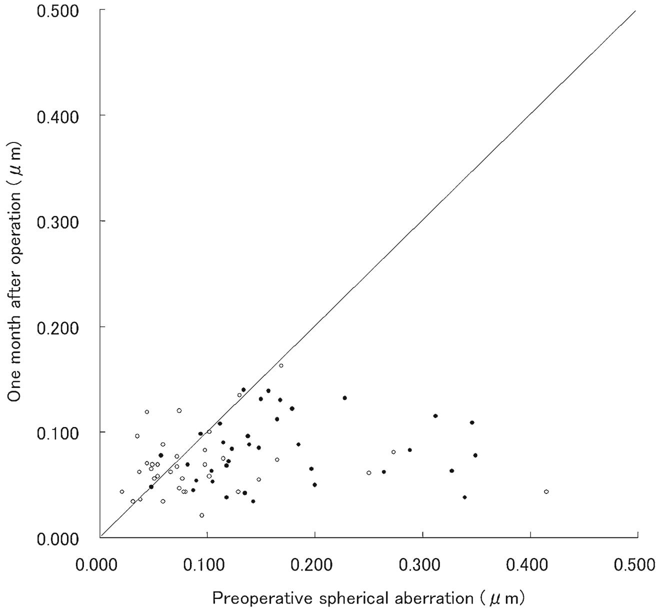

Figure 2. Spherical aberration values obtained preoperatively and 1 month after surgery (○ AR40e, ● ZA9003). Spherical-like aberration was improved in 21 of 37 eyes (57%) implanted with spherical intraocular lenses (IOLs) and in 32 of 37 eyes (89%) implanted with aspherical IOLs. The improvement rate for spherical IOLs was –1.3 ± 62.5% (mean ± standard deviation), and that for aspherical IOLs was 41.0 ± 27.3%. **P* < 0.05 (Mann-Whitney *U* test).

between the improvement rates of the two groups (Fig. 2).

Discussion

In patients with cataracts, contrast sensitivity is decreased even if visual acuity is not, owing to either cortical opacities or nuclear sclerosis of the crystalline lens. This decrease in contrast sensitivity is associated with an increase in higher order aberrations.[2,8] In recent years, the clinical measurement of higher order aberrations has become possible with the development of the wavefront analyzer. Customized correction of refractive defects using wavefront technology was first performed in laser corneal surgery,[9] and has since been performed in lens surgery. Higher order aberrations, along with contrast sensitivity, are thought to be one of the indices that is helpful for evaluating visual function and quality of vision (QOV).

The Tecnis ZA9003 is a relatively new acrylic IOL that requires further study. Most studies that demonstrated improved spherical aberrations with aspherical IOLs used the Tecnis Z9000 silicone IOL (AMO)[10–12] or the AcrySof IQ SN60WF acrylic IOL (Alcon, Fort Worth, TX, USA).[13] In this study, we compared the Tecnis ZA9003 and the Sensar AR40e, both products of AMO. The two A-constants in this case were different because the A-constant depends on the optic shape, which was the only difference between the two IOLs used.

Wavefront analyzers can be classified into three types according to the measurement principle used: the Hartmann-Shack sensor measures the wavefront emitted from the oculus; the Tscherning aberrometer measures the image reflected onto the retina; and analyzers using the optical path difference method apply the principle of skiascopy. The wavefront analyzer OPD-Scan employed in the current study uses the optical path difference method. The OPD-Scan measures a refractive power map of the entire oculus and then calculates the wavefront aberrations with Zernike polynomials.[14] Although it is essential that the refractive power map be measured correctly, the measurement is easily influenced by the iris because more than 1 min of measurement time is required. Thus, measurement errors in the peripheral area tend to be large, especially without pharmacologic pupil dilation. On the other hand, the OPD-Scan can measure the refractive power over a wide range (of the refractive power). The measurement range usually depends on the effective diameter of the device: the larger the effective diameter, the wider the measurement range. An aberrometer with a Hartmann-Shack sensor has a narrower measurement range, while the OPD-Scan can measure high myopia, high astigmatism, keratoconus, and high irregular astigmatism postsurgery. Most studies published to date have used the Hartmann-Shack sensor as the wavefront analyzer for measurement. To our knowledge, this is the first time that a wavefront analyzer based on the optical path difference method has been used to measure the reduction in spherical aberrations in eyes implanted with aspherical IOLs, as compared with eyes implanted with spherical IOLs.

Higher order aberrations have been shown to improve in eyes implanted with aspherical IOLs compared with eyes implanted with spherical IOLs.[10,11] The results of the current study indicate that higher order aberrations in eyes with aspherical IOLs are not necessarily smaller than those in eyes with spherical IOLs. This may be due to the degree of the preoperative higher order aberrations, which was higher in eyes with spherical IOLs than in eyes with aspherical IOLs. Preoperative spherical aberrations, especially, were statistically significant between the two groups ($P < 0.01$). We therefore compared the two groups on the basis of the improvement rate, measured as the degree of improvement obtained postoperatively compared with the values obtained preoperatively. The results indicated that postoperative spherical aberrations in eyes with aspheric IOLs exhibited statistically significant improvement relative to the preoperative spheric aberration ($P < 0.01$). In eyes with spherical IOLs, postoperative spherical aberrations also exhibited improvement, although no statistically significant difference was observed between preoperative and postoperative results ($P = 0.13$). The improvement rate for eyes implanted with aspherical IOLs was 41.0 ± 27.3% (mean ± standard deviation), while that for spherical IOLs was −1.3 ± 42.5%. Aspherical IOLs therefore showed a higher improvement rate that was also of statistical significance ($P < 0.05$). Although the large difference in spherical aberrations observed between the two groups depended on the difference in cataract development, this result was thought to illustrate the greater improving effect on spherical aberrations obtained with aspherical IOLs compared with that obtained with spherical IOLs.

Since Zernike polynomials are orthogonal only over a unit circle, different pupil sizes will yield different expansions. In other words, the higher order aberrations depend on the pupil diameter. In this study, we calculated the RMS values for 4.0-mm pupil diameters for reasons of measurement error and difficulty of measurement. For a 6.0-mm pupil diameter, measurement errors in peripheral area tend to be larger than for a 4.0-mm pupil diameter, and measurement itself becomes difficult in some preoperative patients because of the weakness of the OPD-Scan. However, pupil diameters used for calculation can vary from 3.0 to 6.0 mm,[6,10–12] with 6.0 mm being used most often. According to Schwiegerling,[15] Zernike expansion coefficients can be recalculated for an arbitrary pupil diameter and used for intermeasurement or intersubject comparison of the expansion coefficients, which may require the same pupil diameter between measurements. In this study, we measured and recorded the RMS values only, not the Zernike coefficients. The extant clinical data for spherical IOL were therefore insufficient for this recalculation, and we could not provide a comparison for the 6.0-mm pupil diameter. In future studies, higher order aberrations for a 6.0-mm pupil diameter should also be investigated.

In this study, we measured and analyzed higher order aberrations but not contrast sensitivity. Whereas cataract surgery with IOL implantation increases contrast sensitivity in patients with cataracts, improving both higher order aberrations and contrast sensitivity, the improved values are still inferior to those of healthy young individuals. Aspherical IOLs not only decrease higher order aberrations but improve contrast sensitivity as well;[11,13] in addition to which, the improvement of mesopic contrast sensitivity leads to better subjective QOV. However, Muñoz et al.[10] performed an intraindividual randomized study of 30 patients comparing the Tecnis 9000, the AR40e, and the Stabibag (Ioltech, La Rochelle, France) and reported that visual quality, measured by visual acuity and contrast sensitivity, was not affected. They proposed that differences in the methods employed as well as in material might explain this result. In this study, we used aspherical and spherical IOLs made of the same material. More detailed evaluation and discussion of the contrast sensitivity will therefore be included in future studies.

Fixation of IOLs also affects visual function. The spherical aberration is small and the modulation transfer function is good when an aspherical IOL is well centered, although the dislocation of aspherical IOLs may result in poorer performance than that obtained with spherical IOLs.[16] In addition, if a spherical IOL is dislocated in the eye, the focus position is close to the surface of the retina with no disturbance of ray convergence. On the other hand, dislocation of an aspherical IOL causes detachment of the focus position from the retinal surface and disturbance to the ray convergence, due to, for example, coma aberration. It is therefore important to implant aspherical IOLs well in the bag and properly centered to achieve optimal effect. In this study, slit-lamp examination revealed no malposition of the IOL in any of the patients.

Aspherical IOLs designed to decrease higher order aberrations may decrease unidentified postoperative complaints and contribute to the improvement in QOV. Although many IOLs with additional functions are now available, and additional details regarding the degree to which these IOLs may improve subjective QOV merit discussion, aspherical IOL will become the standard device in the future.

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