

Visual and optical performance of eyes with different corneal spherical aberration implanted with aspheric intraocular lens

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Abstract

- **AIM:** To compare the visual and optical performance of eyes with different corneal spherical aberration (SA) implanted with spherical aberration-free intraocular lens (IOLs).

- **METHODS:** Thirty-six patients with different corneal SA had phacoemulsification with implantation of spherical aberration-free IOLs. Patients were divided into 3 groups according to the value of preoperative corneal SA. Eyes with corneal SA $<0.10\mu\text{m}$ were assigned to group A, those with $0.10 \leq$ corneal SA $<0.20\mu\text{m}$ to Group B, and those with $0.20 \leq$ corneal SA $<0.35\mu\text{m}$ to Group C. Best-corrected visual acuity (BCVA), contrast sensitivity, corneal SA, total ocular aberrations, and depth of focus were recorded 3 months postoperatively. Distance-corrected near and intermediate visual acuity was studied to measure depth of focus.

- **RESULTS:** BCVA and contrast sensitivity were similar between groups. There were no significant differences in distance-corrected near or intermediate visual acuity. Corneal SA was similar before and 3 months after surgery in the 3 groups. With a 5.0mm pupil diameter, root mean square values for total ocular higher-order aberrations (HOAs) were lower in groups A and B than in group C. Total ocular SA was lower in group A than in groups B and C. SA was also lower in group B than in group C. Coma and trefoil were similar between the groups.

- **CONCLUSION:** Implantation of spherical aberration-free IOLs in eyes with different corneal SA results in similar visual performance at BCVA, contrast sensitivity and depth of focus.

- **KEYWORDS:** spherical aberration-free intraocular lens; spherical aberration; contrast sensitivity; cataract

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INTRODUCTION

Previous studies have validated that 4th-order corneal spherical aberration (SA) range from $0.06\mu\text{m}$ to $0.54\mu\text{m}$, with a mean of $(0.280 \pm 0.086)\mu\text{m}$. In one study, 12.3% were between 0.1 and $0.19\mu\text{m}$, 43.9% were between 0.2 and $0.29\mu\text{m}$, and 34.6% were between 0.3 and $0.39\mu\text{m}$ ^[1]. Human lens produces negative SA and counteracts corneal positive SA, however conventional spherical intraocular lens (IOLs) exerts positive SA and increase the spherical aberration of the optical system, resulting in unfavorable visual experience after IOLs replacement^[2]. Aspheric IOLs have been designed to compensate for the positive SA of the cornea, reducing SA of the eye and improving visual quality compared with spherical IOLs^[3]. Today, several aspheric IOLs with different amounts of asphericity are available, including the Tecnis Z9003 (SA= $-0.27\mu\text{m}$ for a 6-mm pupil; Advanced Medical Optics, Inc., Santa Ana, California), AcrySof IQ (SA= $-0.20\mu\text{m}$ for a 6-mm pupil; Alcon Laboratories, Inc., Fort Worth, Texas), and Akreos AO (SA= $0.00\mu\text{m}$ for a 6-mm pupil; Bausch & Lomb, San Dimas, California). Caporossi *et al*^[4] found that the Tecnis Z9003 and AcrySof IQ produced negative SA, which could improve contrast sensitivity and reduce total ocular SA. Akreos AO is aberration-free in both the anterior and posterior aspheric surfaces, and designed to prevent an increase in SA in the eyes^[5,6]. In a comparison of aberration-free IOLs with negative SA, Johansson *et al*^[5] found increased depth of focus, but no significant difference in contrast sensitivity.

The goal of aspheric IOLs is to correct or partially eliminate SA, and thus improve visual quality. However, the amount of residual SA needed to provide the best postoperative visual quality remains controversial. Piers *et al*^[6] suggested a target of $0\mu\text{m}$. Wang *et al*^[7] found that most eyes did not have best image quality at SA of $0\mu\text{m}$, and that optimal SA varied widely. Levy *et al*^[8] reported that the SA in eyes with supernormal vision was $(0.110 \pm 0.077)\mu\text{m}$.

Most studies have compared Akreos AO IOLs to aspheric IOLs with negative SA or spherical IOLs^[4,9]. In this study, we mainly focus on wavefront aberrations, contrast sensitivity, and depth of focus of eyes implanted with spherical aberration-free IOLs in patients with different corneal SA. Our objective was to determine the most suitable patients for implantation of spherical aberration-free IOLs.

MATERIALS AND METHODS

Materials This prospective study was conducted in the Eye Hospital of Wenzhou Medical College in China. The study protocol was approved by the hospital's ethics committee, and all patients provided written informed consent.

This study comprised 40 eyes in 36 patients who could be recruited within 3 months. Inclusion criteria included patients with significant age-related cataracts, aged between 50-75 years, with an axial length between 22mm and 25 mm, and corneal astigmatism lower than 1.5 diopters (D). Exclusion criteria included previous intraocular surgery, ocular trauma, corneal degeneration and dystrophy, optic nerve disease, macular or retinal disease, dry eye, glaucoma, systemic disease (e.g., diabetes or vascular pathology), and operative complications (e.g., capsular rupture, vitreous loss, IOLs not in bag, sulcus fixation).

Methods Patients were divided into 3 groups according to the value of preoperative corneal SA. Eyes with corneal SA $<0.10\mu\text{m}$ were assigned to group A, those with $0.10 \leq$ corneal SA $<0.20\mu\text{m}$ to Group B, and those with $0.20 \leq$ corneal SA $<0.35\mu\text{m}$ to Group C. Preoperative clinical examination was performed by slit-lamp microscopy, and uncorrected visual acuity (UCVA) and best-corrected visual acuity (BCVA) logMAR were tested; intraocular pressure (IOP), axial length and corneal topography were also measured. IOP was measured by non-contact tonometry, axial length was measured with IOL MASTER (Carl Zeiss Meditec, AG, Jena, Germany) in 34 eyes and A-scan ultrasound (BioMedix 6.0, BioMedix, Inc. Paul, Minnesota) in 6 eyes. IOLs power calculation was performed with the Haigis formula, always selecting the closer value to emmetropia.

All procedures were performed by 1 experienced surgeon (Y.E.Z.) using topical anesthesia (Alcaine, Alcon Laboratories, Fort Worth, Texas) with the Alcon Infiniti Vision System (Alcon Laboratories, Inc., Fort Worth, Texas) at the Wenzhou Eye Hospital from June 2009 to December 2009. No surgical complications were reported. A 3.0mm clear corneal incision and a 1.0mm side puncture were made first. After introduction of viscoelastic material (Medical Hyaluronan Gel, Bausch & Lomb Freda, China) into the anterior chamber, a 5.5mm capsulorhexis was made, followed by hydrodissection, phaco-chop technique phacoemulsification using an ozil handpiece, aspiration of cortical masses, anterior and posterior capsular polish, and implantation of Akreos AO IOLs. After removal of the viscoelastic material, the clear cornea wound was closed with hydration.

Postoperative evaluations were performed at 1 day, 1 week, 1 month, and 3 months. UCVA, slit-lamp examination, indirect ophthalmoscopy, and IOP were done at all visits. At 3 months after surgery, BCVA, UCVA, corneal topography, total ocular wavefront aberration, and contrast sensitivity were measured in all patients.

Visual acuity was measured using the Early Treatment Diabetic Retinopathy Study charts under photopic conditions (target luminance of $85\text{cd}/\text{m}^2$). The visual acuity values were converted to the logarithm of the minimal angle resolution units for statistical analysis. All eyes were targeted for emmetropia. Distance-corrected, near (33.3cm), and intermediate (100cm) visual acuity were studied as a measurement of depth of focus^[10].

We measured contrast sensitivity with the CSV-1000E instrument (Vector Vision, Greenville, Ohio, USA)^[11]. This instrument allows testing of contrast sensitivity for distance vision under photopic ($85\text{cd}/\text{m}^2$) and mesopic ($3\text{cd}/\text{m}^2$) conditions as well as mesopic with glare lighting conditions (light illumination is 8.0 Lux). The chart observed by the patient displays sine-wave gratings at 3, 6, 12, and 18 cycles per degree (cpd). The examinations were performed with an undilated pupil and best spectacle corrected visual acuity at 2.5m. For statistical analysis, the measured levels were calculated as log units. The main devices included fixed lighting box, testing board, glaring source located in both sides of the lighting box.

Corneal SA measurements were limited to the central 6.0 mm diameter of the cornea by the Tracey iTrace System (Tracey Technologies, Houston, Texas) before and 3 months after surgery. This equipment is a Placido-based corneal topography analyzer. The backlighted Placido rings are projected onto the corneal tear film, and the image is auto-captured when the device is at the proper working distance and the projected laser beam is centered on the live video image. The iTrace software then defines the ring edges and calculates corneal curvature, corneal refractive power, and corneal wavefront data^[12].

We carried out wavefront analysis of total ocular aberrations using the Tracey iTrace System 3 months after surgery. The iTrace aberrometer projects a thin laser beam through the entrance of the pupil parallel to the eye's line of sight. The location where this beam strikes the retina is measured by capturing the exiting scattered light and focusing it onto X & Y position sensitive linear arrays. Once the iTrace determines the position of point 1, the system moves the laser beam to a new position and determines the location of this point on the retina. This process continues until 256 separate points have been projected through the entrance of the pupil, and is completed in 400 milliseconds faster than the blink of an eye. The iTrace displays the resulting Retinal Spot Pattern. Measurements were obtained after the pupils were dilated with cyclopentolate 1% (Santen Pharmaceutical Co., Ltd. Osaka, Japan). A central pupil diameter of 3.0mm and 5.0

Table 1 Preoperative data

Characteristic	Group A (n=10)	Group B (n=11)	Group C (n=19)	P
Age(a)	67.00±7.60	67.64±6.99	68.58±4.81	0.797
Male /female	6:4	5:5	9:10	0.762
IOLs power (D)	20.15±0.97	20.82±1.62	20.87±1.61	0.441
Preop. corneal SA	0.148±0.046	0.240±0.016	0.316±0.021	0.000

IOLs = intraocular lens; SA = spherical aberration.

Table 2 Mean distance-corrected visual acuity for distance, intermediate, and near vision of eyes implanted with Akreos AO at 3 months

	Group A (n=10)	Group B (n=11)	Group C (n=19)	P
Distance	0.018±0.050	0.022±0.049	0.019±0.047	0.982
Intermediate	0.318±0.030	0.324±0.034	0.328±0.031	0.704
Near	0.386±0.048	0.389±0.040	0.395±0.048	0.878

Table 3 Contrast sensitivities under photopic, mesopic, and mesopic with glare conditions at 3, 6, 12, and 18 cpd between groups

	CPD	Group A	Group B	Group C	P
Photopic condition 85 cd/m ²	3	1.55±0.14	1.51±0.14	1.53±0.18	0.895
	6	1.74±0.12	1.79±0.15	1.71±0.24	0.589
	12	1.51±0.18	1.42±0.17	1.40±0.18	0.283
	18	0.98±0.23	0.85±0.12	0.91±0.24	0.374
Mesopic condition 3 cd/m ²	3	1.39±0.26	1.26±0.11	1.32±0.20	0.349
	6	1.45±0.16	1.54±0.20	1.44±0.24	0.438
	12	1.02±0.24	1.05±0.28	0.99±0.24	0.834
Mesopic with glare condition 3 cd/m ²	18	0.51±0.28	0.55±0.15	0.49±0.23	0.770
	3	1.17±0.14	1.23±0.15	1.16±0.14	0.430
	6	1.25±0.25	1.27±0.19	1.23±0.26	0.876
	12	0.83±0.25	0.85±0.28	0.74±0.17	0.410
	18	0.31±0.23	0.31±0.20	0.30±0.20	0.989

Cpd = cycle per degree; cd/m² = candelas per square meter.

mm was selected for each eye. Measurements were repeated 3 times.

Statistical Analysis Statistical analysis was performed with SPSS 13.0 (SPSS Inc., Chicago, Illinois). After the Kolmogorov-Smirnov test, the data fit the normal distribution. We used ANOVA to evaluate differences among the 3 groups. Post hoc tests with Fisher's least significant difference (LSD) corrections were used for further intergroup comparison. The Chi-square test was used for gender data. $P < 0.05$ was considered statistically significant.

RESULTS

Patients Preoperative data, including age, gender, inserted IOLs power and preoperative corneal SA of the 3 groups, were shown in Table 1. There were no statistically significant differences in age, gender and inserted IOLs power between groups ($P=0.797, 0.762,$ and 0.441 , respectively). We observed a statistically significant difference between the 3 groups in preoperative corneal SA with 6.0mm optical zone diameters ($P=0.000$).

Visual Acuity Three months after surgery, the mean distance BCVA was 0.018 ± 0.050 in group A, 0.022 ± 0.049

in group B and 0.019 ± 0.047 in group C. There was no significant difference between the 3 groups in distance BCVA ($P=0.982$). No significant differences were found between the 3 groups in distance-corrected near ($P=0.878$) and intermediate ($P=0.706$) visual acuity (Table 2).

Contrast Sensitivity As shown in Table 3 and Figure 1, contrast sensitivity was no statistically significant difference between the 3 groups under photopic conditions at any spatial frequency (3, 6, 12 and, 18cpd; $P=0.895, 0.589, 0.283,$ and 0.374 , respectively). Contrast sensitivity was no statistically significant difference between the 3 groups under mesopic conditions at any spatial frequency (3, 6, 12 and, 18cpd; $P=0.349, 0.438, 0.834,$ and 0.770 , respectively). In addition, contrast sensitivity was no statistically significant difference between the 3 groups under mesopic with glare conditions at any spatial frequency (3, 6, 12 and, 18cpd; $P=0.430, 0.876, 0.410,$ and 0.989 , respectively).

Wavefront Analysis Corneal SA before and 3 months after surgery in the 3 groups were show in Table 4 and Figure 2. There were no statistically significant differences between preoperative and postoperative corneal SA ($P=0.116, 0.456,$ and 0.963 , respectively).

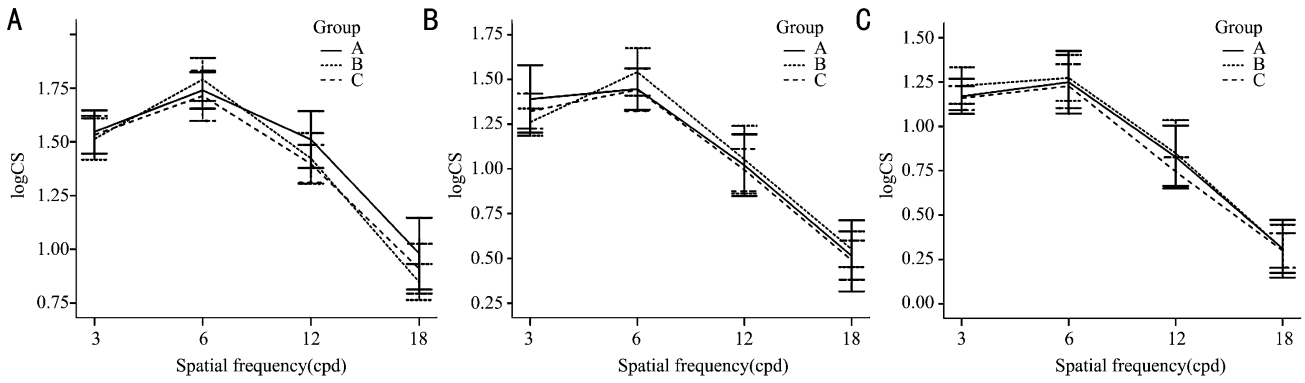


Figure 1 Contrast sensitivity at 3, 6, 12, and 18 cpd between groups A: Photopic; B: Mesopic; C: Mesopic with glare. The contrast sensitivity did not differ significantly at any frequency.

Table 4 The corneal SA before and 3 months after surgery between groups

	Preop. corneal SA	Postop. corneal SA	P
Group A (n=10)	0.148±0.046	0.162±0.059	0.116
Group B (n=11)	0.240±0.0169	0.243±0.023	0.456
Group C (n=19)	0.316±0.021	0.315±0.042	0.963

Table 5 Total ocular higher order aberrations with 3.0mm and 5.0mm pupil diameter 3 months after surgery

	Pupil size(mm)	Group A	Group B	Group C	P
Coma (μm)	3.0	0.091±0.039	0.071±0.047	0.069±0.039	0.370
Trefoil (μm)	3.0	0.078±0.035	0.092±0.039	0.074±0.038	0.450
SA (μm)	3.0	0.023±0.025	0.023±0.023	0.026±0.013	0.879
HOAs (μm)	3.0	0.142±0.031	0.142±0.054	0.136±0.036	0.902
Coma (μm)	5.0	0.176±0.056	0.197±0.036	0.175±0.062	0.556
Trefoil (μm)	5.0	0.197±0.054	0.196±0.053	0.180±0.067	0.706
SA (μm)	5.0	0.163±0.029	0.234±0.060	0.317±0.055	0.003 [†]
					0.000 [‡]
					0.000 ^{††}
HOAs (μm)	5.0	0.442±0.026	0.492±0.076	0.560±0.075	0.098 [†]
					0.000 [‡]
					0.011 ^{††}

SA = spherical aberration; HOAs = higher-order aberrations.

[†] Between Group A and Group B.

[‡] Between Group A and Group C.

^{††} Between Group B and Group C.

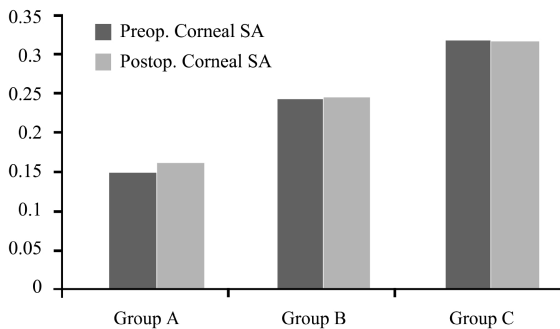


Figure 2 Comparison of corneal SA before and 3 months after surgery between the 3 groups with 6.0mm optical zone diameters.

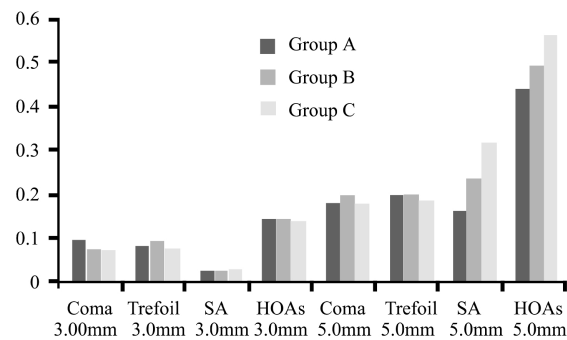


Figure 3 Total ocular higher order aberrations with 3.0mm and 5.0mm pupil diameter at 3 months after surgery.

The postoperative wavefront analysis, including total ocular mean HOAs RMS values, SA, coma and trefoil were shown in Table 5 and Figure 3. With a 5.0mm pupil diameter, HOAs RMS values were lower in groups A and B than that

in group C (0.442±0.026μm, 0.492±0.076μm, and 0.560±0.075μm, respectively; $P=0.000$, $P=0.011$). SA was lower in group A than in groups B and C (0.163±0.029μm, 0.234±0.060μm, 0.317±0.055μm, respectively; $P=0.003$, $P=0.000$).

The SA was also lower in group B than in group C ($P=0.000$). Coma and trefoil were similar between groups ($P=0.556$ and 0.706). With a 3.0mm pupil, HOAs RMS values, SA, coma and trefoil were similar between groups ($P=0.370$, 0.450 , 0.879 , and 0.902 , respectively).

DISCUSSION

Wavefront aberrometry is now a well-accepted and widely-used tool to assess visual quality [13,14]. Ocular SA is composed of corneal SA which is usually positive, and intraocular SA [15]. Aspheric IOLs designed with 0 or negative SA can reduce or eliminate corneal SA after removal of the crystalline lenses [16]. According to Dick [17] aspheric IOLs offer improved functional vision to patients, but may need to be better targeted to accommodate the large range of corneal SA. Today, customized aspheric IOL implantations have yet to be adopted in many hospitals. Corneal SA is not measured before surgery, and the same type of aspheric IOLs are implanted in different individuals. To study the SA values of eyes that would get best postoperative visual quality, we observed the visual and optical performance of eyes with different corneal SA implanted with the same type of spherical aberration-free IOLs. The uniformity of pre- and post-operative corneal SA demonstrates that corneal incision exerts no influence to corneal SA, which is the premise of grouping principle in this study.

Akreos AO are designed to prevent the addition of positive SA after surgery. The stability of corneal SA before and after surgery is a precondition of customized grouping with preoperative corneal SA. Marcos *et al* [18] and Guirao *et al* [19] found that with 3.2mm and 3.5mm corneal incisions, corneal SA did not change significantly. Negishi *et al* [20] reported no statistically significant difference between preoperative and postoperative corneal SA with incisions of 2.8mm and 2.2mm. Our study confirms prior findings. With a 3.0mm corneal incision, there were no statistically significant differences between preoperative and postoperative corneal SA in the 3 groups, indicating that customized grouping based on preoperative corneal SA is feasible.

Two studies [2,21] found better BCVA in low SA eyes with aspheric IOLs than in eyes with spherical IOLs. However, other comparisons showed no significant differences [5,6,22]. Montés-Micó *et al* [23] reported that either no differences in visual acuity are found between aspheric and spherical IOLs or that visual performance metrics are not accurate enough to detect subtle visual changes due to SA reduction. In our study, BCVA was not significantly different among groups with different degrees of corneal SA, indicating BCVA is not the most sensitive index to SA. So contrast sensitivity and glare tests are used in this study to obtain objective and extended assessment of visual function. These are better predictors of visual alterations than traditional high-contrast visual acuity measurements under photopic conditions [12]. Both in the laboratory and in clinical studies, aspheric IOLs are known to reduce ocular SA, improve contrast sensitivity,

and improve night driving performance [2,23]. However, recent studies [24,25] report that a reduction in SA does not automatically lead to improved contrast sensitivity. In our study, ocular HOA and SA were significantly different among the 3 groups. Interestingly, the contrast sensitivity outcomes were relatively equal at any spatial frequency under photopic, mesopic, and mesopic with glare conditions. Several possible explanations address this lack of difference in contrast sensitivity. First, the difference of SA between groups was not large enough to cause changes in contrast sensitivity. Muñoz *et al* [26] suggested that testing methods may not be sensitive enough to detect subtle differences in contrast sensitivity. In this regard, some comparative studies report no differences between aspheric and spherical IOLs in contrast sensitivity, despite significant reductions in SA. Jin-A Choi *et al* showed an intraindividual difference (Δ_i) for SA of $0.06\mu\text{m}$ (4.0mm pupil) [9]. Kasper *et al* [25] found that Δ_i SA was $0.04\mu\text{m}$ (3.8mm pupil). In our study, Δ_i SA between the groups A and B was $0.06\mu\text{m}$ (5.0mm pupil). The Δ_i SA between the groups B and C was $0.07\mu\text{m}$ (5.0mm pupil), and the Δ_i SA between the groups A and C was $0.13\mu\text{m}$ (5.0mm pupil). Other studies have reported that aspheric IOLs resulted in significantly lower ocular SA and significantly better mesopic contrast sensitivity, i.e., Δ_i SA of $0.41\mu\text{m}$ (4.6mm pupil) [27]. In that all calculations and measurements of SA are with a 5.0mm pupil, another reason might be pupil size. In fact, the average pupil size could not be as large as 5.0mm when measuring contrast sensitivity, not even under scotopic conditions [13,28]. This decreases the impact of SA [29]. In our study, we did not measure pupil size when we measured contrast sensitivity. This might be a potential limitation of our study.

Data indicate that some positive spherical aberration may provide better depth of focus [30]. Some studies found that the depth of focus was significantly larger in eyes with spherical IOLs compared with negative SA aspheric IOLs [10,31]. In a comparison of the Tecnis Z9000 IOLs and the Akreos AO IOLs, Johansson *et al* [5] reported that the latter provided a larger depth of focus. They also showed that a higher amount of SA resulted in a better depth of focus. Santhiago *et al* [32] reported a comparison of the Akreos AO IOLs and the Akreos Fit IOLs, he found there was a significantly different amount of spherical aberration between the 2 IOLs while the depth of focus was similar. In our study, the depth of focus was similar among the 3 groups, although the difference in SA was statistically significant. After implantation of a spherical aberration-free IOL that does not generate negative SA to compensate for the positive SA of the cornea, we found a higher amount of SA in the optical system, which produced no significant reduction in depth of focus. Otherwise perhaps the difference of SA among groups was not large enough to cause changes in depth of focus. In summary, the results of our study suggest that implantation of spherical aberration-free IOLs in eyes with

different corneal SA provided similar visual performance. Perhaps the spherical aberration-free IOLs fit different eyes with different corneal SA. Larger controlled studies with spherical IOLs as well as negative SA aspherical IOLs are warranted. It will take more research to determine the amount of residual SA that will provide the best postoperative visual quality.

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