ARTICLE

Using adaptive optics to optimize the spherical aberration of eyes implanted with EDOF and enhanced monofocal intraocular lenses

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Purpose: To assess the effect of change in ocular spherical aberration (SA) with adaptive optics on visual acuity (VA) at different defocus after implantation of extended depth-of-focus (EDOF) and enhanced monofocal intraocular lenses (IOLs).

Settings: Narayana Nethralaya Eye Hospital, Bangalore, India.

Design: Prospective, longitudinal, observational.

Methods: 80 eyes (40 patients) that had cataract surgery were included in the study. 40 eyes were implanted with Eyhance EDOF IOLs and the remaining with Vivity EDOF IOLs. Baseline ocular aberrations were measured with a visual adaptive optics aberrometer, then the optimal SA was determined by increasing it in steps of −0.01 μm up to −0.1 μm until the maximum improvement in near distance VA was observed for a given eye. Then the defocus curve for each eye was measured after modifying the ocular SA by magnitude equal to optimal SA.

Results: Most of the eyes accepted a negative induced SA of −0.05 μm (Eyhance group: 67.6%; Vivity group, 45.2%). In the Eyhance group (dominant eyes), VA improved at −2 diopters (D) ($P < .02$) only and degraded at 0 D, +0.5 D, and +1 D defocus ($P < .05$). In the Vivity group, the VA remained unchanged at all defocus ($P > .05$). In the Eyhance group (nondominant eyes), VA improved at −3.5 D defocus only and degraded at +1.5 D and +2 D defocus ($P < .05$). In the Vivity group, VA improved at −2.5 D defocus ($P < .05$) only.

Conclusions: A negative induced SA of −0.05 μm in implanted eyes was optimal for a slight improvement in distance-corrected near and intermediate VA without any significant decrease in baseline distance-corrected VA.

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Cataract surgery is the most commonly performed ophthalmic surgery in the world.[1] However, presbyopia correction remains the holy grail of cataract surgery. In the past few years, extended depth-of-focus (EDOF) intraocular lenses (IOLs) are being used by surgeons and claim to provide patients with good distance, intermediate, and near vision. Enhanced monofocal IOL aims to bridge the gap in performance between standard monofocal IOLs and EDOF IOLs as the latter may provide better distance-corrected near visual acuity (VA).[2] For intermediate vision, both enhanced and EDOF IOLs provide similar performance among patients.[2] Although these IOLs provide excellent intermediate vision, the quality and quantity of near vision may be inadequate.[3,4] Some patients may still need reading spectacles after implantation of EDOF IOLs.[5] Thus, all patients expecting spectacle independence may not benefit from EDOF IOLs. Another cause of patient dissatisfaction after cataract surgery is poor quality of vision despite good VA postoperatively.[6,7] Higher-order aberrations (HOAs), for example, coma, trefoil, and spherical aberration (SA), can affect the quality of vision. The SA is one of the major HOAs in human eyes.[8] In younger eyes, the cornea accounts for some degree of positive SA which is compensated by negative SA of the clear crystalline lens.[9–13] This helps in ensuring optimal visual function and optical performance. With aging and a resultant change in the optical properties of the crystalline lens, the magnitude of SA increases.[13–16] Conventional spherical IOLs increase the total positive SA of the eye.[10,17,18]

Aspheric intraocular lenses were introduced to compensate for the positive SA of the cornea.[19] These aspheric IOLs induce either a negative or neutral SA, thereby eliminating or

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maintaining the positive corneal SA. Aspheric IOLs can reduce the total ocular SA and improve the visual performance.[20] Altering SA and its effect on near vision may have a role in correction of presbyopia.[19,21–24] A pseudophakic eye can be an ideal candidate for modulating SA to identify its effect on optical performance of an IOL since the inherent SA of the IOL is known by design, and this could be used as a baseline for simulation of additional SA. The AcrySof IQ Vivity IOL is an EDOF, single-piece, aspheric, hydrophobic, acrylic IOL with an optical diameter of 6 mm and an overall diameter of 13 mm. It uses the unique X-wave or wavefront shaping technology for providing an extended depth of focus.[25] The optic of the IOL also induces a negative SA to compensate for the positive SA of a cornea. Likewise, the TECNIS Eyhance IOL (Johnson & Johnson Vision) is a single-piece, hydrophobic, biconvex IOL which provides an improved depth of focus compared with the standard monofocal IOLs.[26]

By inducing negative SA, these IOLs attempt to reduce the postoperative SA by aiming to correct the mean corneal SA. Studies suggest that ocular SA increases the depth of focus and tolerance to defocus.[22,27] However, the value of optimal change in SA after implantation of an enhanced and EDOF IOL to achieve an improvement in near VA and intermediate VA without a significant worsening of distance VA has not been reported in patients. Newer optical imaging technologies, such as adaptive optics (visual adaptive optics [VAO] simulator, Voptica Inc.), can measure and modify aberration profiles of patients noninvasively and simulate changes in near vision with changes in specific aberrations. In our study, we used the adaptive optics simulator to identify whether inducing a negative SA in pseudophakic eyes would affect visual acuities at different distances. The aim of our study was to determine whether near vision can be improved in emmetropic pseudophakic eyes implanted with EDOF IOLs without compromising distance vision after inducing additional negative SA using visual adaptive optics. We also measured how the induction of a negative SA would affect the subjective tolerance to defocus. Negative SA has the potential to increase the depth of focus on a patient-specific basis, and this has been shown in patients using adaptive optics vision testing.[28] This is the first study to identify whether visual performance of an eye implanted with EDOF or enhanced monofocal IOL can be improved further by modulating the ocular SA.

METHODS

This prospective, observational, and cross-sectional study was conducted at Narayana Nethralaya Eye Hospital, Bangalore, India, according to the tenets of the Declaration of Helsinki and after approval by the Institutional Ethics Committee (Approval No.: EC/NEW/INST/2021/1510) of Narayana Nethralaya Eye Hospital, Bangalore. A total of 80 eyes of 40 patients having undergone a bilateral uncomplicated clear corneal phacoemulsification procedure with EDOF IOL implantation, over a period of 6 months (September to December 2022), were included in this study. This included 20 patients (40 eyes) having undergone implantation of the AcrySof Vivity IOL (Alcon Laboratories, Inc.) and another 20 patients (40 eyes) with implantation of the TECNIS Eyhance IOL (Johnson & Johnson Vision). All surgeries were conducted in the hospital by a single experienced surgeon (N.S.). Those patients having preexisting ocular or retinal pathologies and those not willing to give consent were excluded from the study. These patients underwent subjective refraction by a single experienced optometrist, followed by slitlamp and undilated fundus examination. Then, these patients were subjected to vision assessment and simulation on a VAO simulator. After the vision simulation, patients underwent dilated optical coherence tomography imaging (1050-nm swept-source optical coherence tomography) for ruling out retinal pathology, if any. Patients with pupils smaller than 3 mm were excluded as the response of the human eye with pupils smaller than 3 mm to induced aberrations was insignificant, and hence, the VAO simulator was designed for a pupil size of 3 mm or greater.[29]

Apparatus

The VAO simulator consists of a Hartmann-Shack aberrometer and spatial light modulator for measuring and simulating aberrations through the recorded eye-specific pupil diameter.[30] The spatial light modulator is used to modify the measured aberrations and perform objective vision testing at different target distances. The VAO simulator can measure aberrations through pupil diameters ranging from 3 to 8 mm. However, the device restricts the modulation of aberrations to 4.5 mm in diameter only. If any eye had a pupil diameter greater than 4.5 mm, then the VAO simulator restricted the simulation of aberrations to a 4.5-mm size only. If the pupil diameter was less than 4.5 mm, then the VAO simulator used the in situ diameter of an eye for simulations. Three repeat measurements of the ocular wavefront aberration were obtained, and the mean aberrations were quantified with Zernike polynomials up to order 6 by the VAO simulator. Uncorrected VA was then recorded on the VAO simulator using an in-built VA chart at different reading defocus: 2.5 diopters (D) (40 cm or near), 1.5 D (66.7 cm or intermediate), and 0 D (infinity or distance). The subjective manifest distance refraction of the patient as tested at 6 m by the single experienced optometrist was entered on the VAO simulator. Thus, this allowed the corrected distance VA of the eye to be used as a baseline for successive measurements with the VAO simulator. Then, adaptive optics simulation of VA was performed by modulating the in situ SA at distance. The following were the simulation steps: (1) Only SA of the measured wavefront was modulated in steps of −0.01 μm (range −0.01 to −0.1 μm), and distance corrected VA was retested at different reading targets in the same order. (2) Distance, intermediate, and near vision for each incremental SA (ΔSA) was noted. (3) We noted the optimal incremental threshold value of SA (ΔSA) at which the distance-corrected near and intermediate VA improved with minimal or no worsening of distance vision from the baseline distance-corrected VA. All measurements were performed at 1 month postoperatively. (4) After identifying the optimal threshold incremental SA (ΔSA), the uniocular distance-corrected spherical defocus curves were tested between +2 D and −3.5 D in the VAO simulator under mesopic room lighting conditions. However, the VAO simulator viewfinder shields the eye effectively from ambient light, and this had minimal bearing on the measurements of the VAO simulator. (5) The VA was recorded in LogMAR at all distances. The aberration measurement and VA testing were conducted at 100% contrast in the VAO device display and constant lighting conditions.

The dominance of the eyes was determined by the hole in the card test instructing the patient to fixate 1 letter at distance through a hole between his/her hands having their arms outstretched. Then, the patient's eyes were occluded alternately, and the patient was asked to report when the target was visible. The dominant eye was identified as the eye that could maintain the fixed letter centered within the hole in the card.

Statistical Analysis

The parameters were summarized as median and interquartile range (IQR) after confirming non-normality of distribution. If data were normally distributed, then mean and standard deviation

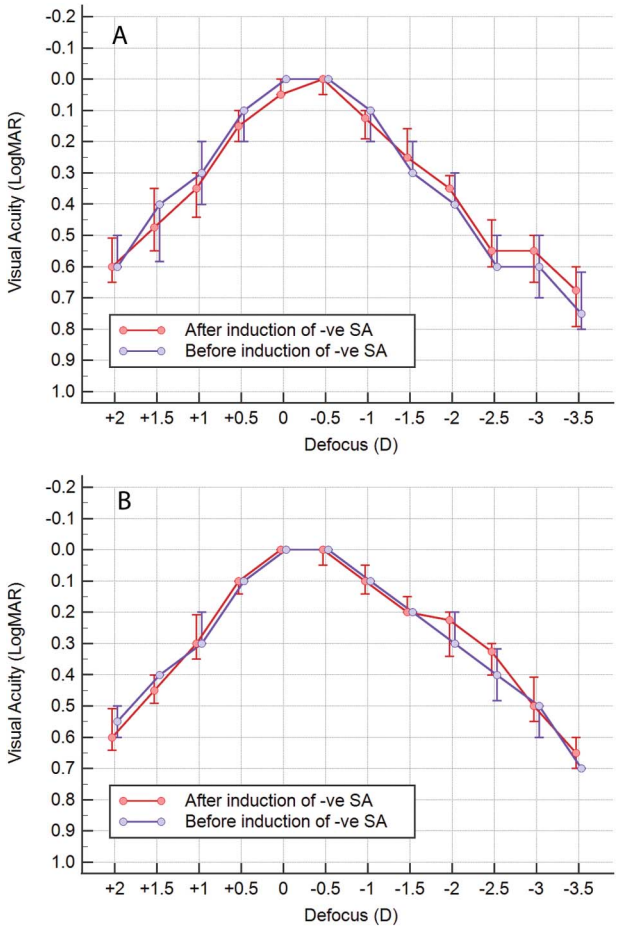

Figure 1. *A*: Visual acuity of dominant eyes in the Eyhance group before and after induction of negative ocular SA. This figure shows the VA of the eye measured at respective optimal SAs and pupil diameters for each eye. If any eye had a pupil diameter greater than 4.5 mm, then simulation was restricted to 4.5-mm diameter only. *B*: VA of dominant eyes in the Vivity group before and after induction of negative ocular SA. This figure shows the VA of the eye measured at respective optimal SAs and pupil diameters for each eye. If any eye had a pupil diameter greater than 4.5 mm, then simulation was restricted to 4.5-mm diameter only. SA = spherical aberration

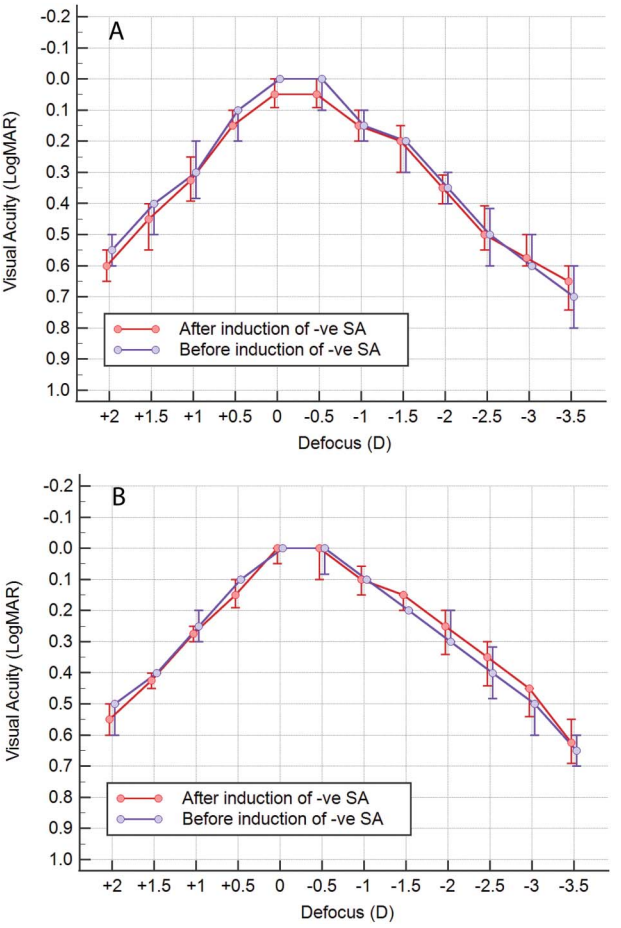

Figure 2. *A*: VA of nondominant eyes in the Eyhance group before and after induction of negative ocular SA. This figure shows the VA of the eye measured at respective optimal SA and pupil diameters for each eye. If any eye had a pupil diameter greater than 4.5 mm, then simulation was restricted to 4.5-mm diameter only. *B*: VA of nondominant eyes in the Vivity group before and after induction of negative ocular SA. This figure shows the VA of the eye measured at respective optimal SAs and pupil diameters for each eye. If any eye had a pupil diameter greater than 4.5 mm, then simulation was restricted to 4.5-mm diameter only. SA = spherical aberration

were used. Kruskal-Wallis test was used to compare parameters between the 2 groups. Friedman test was used to analyze data within a group before and after induction of negative SA. Separate analyses were conducted for dominant and nondominant eyes. A P value less than 0.05 was considered statistically significant. MedCalc v. 20.015 (Medcalc Software bvba) was used for all statistical analyses.

RESULTS

Eighty eyes of 40 patients were included in the study. The median age of 28 men (70%) and 12 women (40%) was 66 years (range, 40 to 78 years). The median preoperative spherical refractive error in the Eyhance group was 0 D (IQR, −2.5 to 0.88 D; range, −6 to 2.5 D) and 0 D (IQR, −1.75 to 2 D; range, −5 to 3.5 D) in the Vivity group. There was no statistical difference in preoperative spherical refractive error between the groups (P = .12). The median preoperative cylindrical refractive error in the Eyhance group was −0.5 D (IQR, −0.75 to 0 D; range, −1.5 to 3.25 D) while in the Vivity group, it was 0 D (IQR, −0.8 to 0 D; range, −2 to 0 D). There was no statistical difference in preoperative cylindrical refractive error between the groups (P = .63). The postoperative median spherical equivalent refractive error in the Eyhance group was 0 D (IQR, −0.25 to 0.25 D; range, −0.75 to 0.5 D) while in the Vivity group, it was −0.25 D (IQR, −0.44 to 0 D; range, −1.25 to 0.38 D). There was significant statistical difference in postoperative spherical equivalent refractive error between the groups (P = .02). However, this difference was clinically insignificant.

In the Eyhance group, the median pupil diameter was 4.5 mm (IQR, 4 to 4.5 mm; range, 3 to 4.5 mm) and 4.5 mm (IQR, 4 to 4.5 mm; range, 3 to 4.5 mm) in dominant and nondominant eyes (P = .71), respectively. In the Vivity group, the median pupil diameter was 4.5 mm (IQR, 3.5 to 4.5 mm; range, 3 to 4.5 mm) and 4.25 mm (IQR, 3.75 to 4.5 mm; range, 3 to 4.5 mm) in dominant and nondominant eyes (P = .74), respectively. The postoperative median

Table 1. VA at different defocus before induction of negative ocular spherical aberration

Defocus (D)	Eyhance			Vivity		
	Dominant (n = 20)	Nondominant (n = 20)	*P* value[a]	Dominant (n = 20)	Nondominant (n = 20)	*P* value[a]
+2	0.6 (0.5, 0.6)	0.55 (0.5, 0.6)	.87	0.55 (0.5, 0.6)	0.5 (0.5, 0.6)	.34
+1.5	0.4 (0.35, 0.6)	0.4 (0.4, 0.55)	.87	0.4 (0.4, 0.45)	0.4 (0.4, 0.4)	.5
+1	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	.74	0.3 (0.2, 0.35)	0.25 (0.2, 0.3)	.55
+0.5	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	.7	0.1 (0.1, 0.15)	0.1 (0.1, 0.1)	.7
0	0 (0, 0)	0 (0, 0)	1	0 (0, 0)	0 (0, 0)	.3
−0.5	0 (0, 0.05)	0 (0, 0.1)	.5	0 (0, 0)	0 (0, 0.1)	.47
−1	0.1 (0.1, 0.2)	0.15 (0.1, 0.2)	.68	0.1 (0.1, 0.1)	0.1 (0.1, 0.15)	.49
−1.5	0.3 (0.2, 0.3)	0.2 (0.2, 0.3)	.27	0.2 (0.15, 0.2)	0.2 (0.15, 0.2)	.87
−2	0.4 (0.3, 0.4)	0.35 (0.3, 0.4)	.75	0.3 (0.2, 0.3)	0.3 (0.2, 0.3)	1
−2.5	0.6 (0.5, 0.6)	0.5 (0.4, 0.6)	.23	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	.93
−3	0.6 (0.5, 0.7)	0.6 (0.5, 0.65)	.42	0.5 (0.5, 0.6)	0.5 (0.5, 0.6)	.62
−3.5	0.75 (0.6, 0.8)	0.7 (0.6, 0.8)	.39	0.7 (0.65, 0.7)	0.65 (0.6, 0.7)	.2

[a]Kruskal-Wallis test

spherical error in the Eyhance group was 0 D (IQR, 0 to 0.5 D; range, −0.75 to 0.75 D) while in the Vivity group, it was 0 D (IQR, 0 to 0 D; range, −1.25 to 1 D). There was no statistical difference in postoperative spherical refractive error between the groups (P = .11). The postoperative median cylindrical error in the Eyhance group was −0.5 D (IQR, −0.5 to 0 D; range, −1 to 0.75 D) while in the Vivity group, it was −0.5 D (IQR, −0.5 to 0 D; range, −1.5 to 0 D). There was no statistical difference in postoperative cylindrical refractive error between the groups (P = .29).

No significant difference was seen in optimal SA induced between both groups (P = .9). In the Eyhance group, median optimal induced SA was −0.05 μm (range, −0.01 to −0.1 μm) and approximately 2.5%, 7.5%, 5%, 75%, and 10% of the eyes required an optimal induced SA of −0.01 μm, −0.02 μm, −0.03 μm, −0.05 μm, and −0.1 μm, respectively. Similarly, in the Vivity group, median optimal induced SA was −0.05 μm (range, −0.02 to −0.15 μm) and approximately 10%, 17.5%, 50%, 17.5%, and 5% of the eyes required an optimal induced SA of −0.02 μm, −0.03 μm, −0.05 μm, and −0.1 μm, respectively. Thus, an optimal induced SA of −0.05 μm for a 4.5-mm pupil size was observed for most of the eyes. Figure 1A and 1B shows the defocus curves for the dominant eyes (before and after induction of negative SA) in the Eyhance group and Vivity group, respectively. Similarly, Figure 2A and 2B shows the defocus curves for the nondominant eyes in the Eyhance and Vivity groups, respectively. Overall, a decrease in VA was observed with defocus in both groups before and after induction of negative SA, irrespective of dominance (Figures 1 and 2). Table 1 summarizes that the VA was similar between the dominant and nondominant eyes in both the Eyhance and Vivity groups before induction of negative SA (P > .05). A similar trend was observed after induction of negative SA through the VAO simulator (P > .05 in Table 2).

Table 3 summarizes the change in VA after induction of negative SA in the Eyhance and Vivity groups only among the dominant eyes. In the Eyhance group, a significant improvement in VA was observed at a defocus of −2 D (P <

Table 2. VA at different defocus after induction of negative ocular spherical aberration

Defocus (D)	Eyhance			Vivity		
	Dominant (n = 20)	Nondominant (n = 20)	*P* value[a]	Dominant (n = 20)	Nondominant (n = 20)	*P* value[a]
+2	0.6 (0.5, 0.65)	0.6 (0.55, 0.65)	.69	0.6 (0.5, 0.65)	0.55 (0.5, 0.6)	.52
+1.5	0.48 (0.35, 0.55)	0.45 (0.4, 0.55)	.67	0.45 (0.4, 0.5)	0.43 (0.4, 0.48)	.67
+1	0.35 (0.28, 0.45)	0.33 (0.23, 0.43)	.6	0.3 (0.2, 0.38)	0.28 (0.23, 0.33)	.74
+0.5	0.15 (0.1, 0.2)	0.15 (0.1, 0.18)	.91	0.1 (0.1, 0.2)	0.15 (0.1, 0.2)	.23
0	0.05 (0, 0.05)	0.05 (0, 0.1)	.97	0 (0, 0)	0 (0, 0.05)	.07
−0.5	0 (0, 0.08)	0.05 (0, 0.1)	.72	0 (−0.03, 0.08)	0 (0, 0.1)	.37
−1	0.13 (0.1, 0.2)	0.15 (0.08, 0.2)	.5	0.1 (0.05, 0.15)	0.1 (0.05, 0.15)	.58
−1.5	0.25 (0.15, 0.28)	0.2 (0.15, 0.3)	.48	0.2 (0.13, 0.2)	0.15 (0.13, 0.23)	.76
−2	0.35 (0.28, 0.38)	0.35 (0.3, 0.4)	.58	0.23 (0.2, 0.35)	0.25 (0.18, 0.35)	.9
−2.5	0.55 (0.45, 0.6)	0.5 (0.4, 0.58)	.21	0.33 (0.3, 0.4)	0.35 (0.28, 0.45)	.92
−3	0.55 (0.5, 0.65)	0.58 (0.5, 0.6)	.76	0.5 (0.4, 0.55)	0.45 (0.45, 0.55)	.54
−3.5	0.68 (0.6, 0.8)	0.65 (0.6, 0.75)	.42	0.65 (0.6, 0.7)	0.63 (0.55, 0.7)	.22

[a]Kruskal-Wallis test

Table 3. Change in VA of dominant eye at different defocus due to induction of negative ocular spherical aberration

	Eyhance (dominant)		Vivity (dominant)	
Defocus (D)	Difference (after − before)	*P* value[a]	Difference (after − before)	*P* value[a]
+2	0.03	.33	0.03	.12
+1.5	0	.34	0.05	.27
+1	0.05	.02*	0	.1
+0.5	0	.048*	0	.47
0	0.03	<.001*	0	—
−0.5	0	.3	0	.97
−1	0	.76	0	.37
−1.5	0	.32	0	.2
−2	−0.05	.02*	0	.42
−2.5	−0.05	.44	−0.05	.09
−3	−0.05	.18	−0.03	.45
−3.5	−0.03	.08	0	.64

*Statistically significant
[a]Wilcoxon test (paired samples)

.02) only while a degradation in VA was observed at 0 D, +0.5 D, and +1 D defocus ($P < .05$). In the Vivity group, the VA remained unchanged at all defocus after induction of negative SA ($P > .05$). Table 4 summarizes the change in VA after induction of negative SA in the Eyhance and Vivity groups only among the nondominant eyes. In the Eyhance group, a significant improvement in VA was observed at −3.5 D defocus while a significant degradation in VA was observed at +1.5 D and +2 D defocus ($P < .05$). In the Vivity group, a significant improvement in VA was observed at −2.5 D defocus ($P < .05$).

DISCUSSION

Apart from the continuous technological advancements in cataract surgery techniques, several strategies have been used to provide patients with optimum distance, intermediate, and near vision. Many of these include enhancing the depth of field by inducing aberrations and optical errors.[31–37] Conventional spherical IOLs add positive SA to the existing corneal aberrations and thereby increase the total SA of the eye.[17,18,38] The advent of aspheric IOLs have helped introduce negative SA, thereby reducing the total postoperative SA. An aspheric surface as the name suggests is a surface that is not spherical. In an aspheric lens, the rays of light passing through the center focus at the same point as the rays passing through the periphery of the lens. Previous studies showed that SA increases the depth of focus and tolerance to defocus.[39,40] A negative ocular SA causes an increase in the power of eye centrally and creates a clearer near image when the pupil constricts. By contrast, a positive SA causes a weaker power of the eye centrally and reduces the quality of image for near distance. This is why a negative SA in an aspheric IOL may be more advantageous than a positive SA. These effects are true only if the patient is corrected for his/her paraxial power. However, the value of optimal change in SA for these IOLs to achieve an improvement in near VA and intermediate VA without a

Table 4. Change in VA of nondominant at different defocus due to induction of negative ocular spherical aberration

	Eyhance (nondominant)		Vivity (nondominant)	
Defocus (D)	Difference (after − before)	*P* value[a]	Difference (after − before)	*P* value[a]
+2	0.05	<.01*	0	.04*
+1.5	0.03	<.01*	0.03	.15
+1	0.05	.09	0	.01*
+0.5	0	.19	0.03	<.01*
0	0	.01*	0	.047*
−0.5	0	.7	0	.25
−1	0	.33	0	.5
−1.5	0	.36	−0.03	.13
−2	0	.52	−0.05	.09
−2.5	0	.16	−0.05	<.01*
−3	−0.03	.11	−0.05	.11
−3.5	−0.03	.02*	−0.05	.12

*Statistically significant
[a]Wilcoxon test (paired samples)

significant worsening of distance VA is still unclear. We aimed to identify whether the visual performance of an EDOF IOL can be improved by modulating the SA.

The AcrySof IQ Vivity IOL is a biconvex aspheric foldable IOL with unique wavefront shaping technology to provide an extended depth of focus. The anterior surface of the IOL is designed with negative SA to compensate for the positive SA of the cornea. The TECNIS Eyhance IOL is a biconvex aspheric foldable IOL that slightly improves the depth of focus as compared with a conventional monofocal IOL. Bakaraju et al. attempted to study the relationship between the sign of SA and the corresponding depth-of-focus values around best focus at 3 different spatial frequencies.[39] The study reported that both positive and negative SAs increased the depth of focus.[39] Furthermore, higher levels of negative SA, whether intrinsic or induced, led to marginally higher levels of depth of focus than when the same magnitude of positive SA was present. Keeping this in mind, we induced a negative SA using the VAO simulator to identify whether the change in SA could contribute to any change in the visual performance of an EDOF IOL.

Our study showed that inducing a negative SA led to a significant statistical improvement in the Eyhance and Vivity groups in the range of −2 to −3.5 D defocus. However, this improvement may not be considered as clinically significant. Most of the eyes accepted an induced negative SA of −0.05 μm or less. Thus, it may appear that the design of these 2 EDOF IOLs was optimal for patients who do not want a higher impairment of their distance vision. In our previous work, we determined the optimum negative SA induction required to improve near and intermediate VA of presbyopic eyes among normal patients and those with diabetes.[40] We found the mean incremental threshold SA (ΔSA) to be similar in both the groups, which was −0.15 μm and greater than the threshold of −0.05 μm observed in this study. This could be attributed to the inherent SA of the respective IOLs in both studies since a value of −0.15 μm at 4.5 mm has been reported as the cutoff for decreasing 1 line of VA.[41] Induction of SA to improve near and intermediate vision without allowing the deterioration of distance vision is a subject of extensive study. Zhelenyak et al. found that induction of negative SA had greater benefit at near vision while positive SA had greater benefit at intermediate vision.[42] Rocha et al. established that induction of both positive and negative SAs increased the depth of focus.[32]

The results of our study re-established the fact that induction of negative SA with patient-specific testing of visual optics may provide marginally improved near and intermediate VA. However, our study also has a few limitations. A prospective comparative study design with monofocal, other EDOF, and trifocal IOLs to study the effect of a targeted SA profile for improving near and intermediate VA would be of significant benefit for optimizing outcomes. We also excluded eyes with pupil diameter below 3 mm. This is a limitation of the study since a significant proportion of the patients have pupil diameter below 3.5 mm and the Eyhance IOL induces SA for pupil size less than 3 mm by design.[43] Our study holds tremendous promise in customizing the design of the IOLs based on patient-specific SA values. Further studies evaluating the role of contrast sensitivity and its correlation to changes in VA at the threshold value of negative SA need to be performed.

WHAT WAS KNOWN

- Enhanced monofocal and EDOF IOLs are designed to provided better near and intermediate visual acuity to patients.
- Modulation of ocular SA could provide better near and intermediate VA.

WHAT THIS PAPER ADDS

- Most study patients accepted a change in ocular SA by -0.05 micrometer or less with marginal improvement in visual acuity at near and intermediate distances.
- Current design of Eyhnace and Vivity IOls appeared to be optimal for most patients in our study.

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