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Change of Spherical Aberration with Aspheric Soft Contact Lens Wear

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Purpose: To investigate ocular higher order aberrations (HOA) and spherical aberration changes caused by an aspheric soft contact lens designed to reduce spherical aberration (SA) of the eye. **Methods**: Fifty subjects who have successfully experienced soft contact lenses were refitted with aspheric design (Soflens Daily Disposable: SDD, Bausch+Lomb) soft contact lens. Ocular higher order aberrations (HOA) and stand alone SA were measured and analyzed for a 4-mm pupil size using Wave-Scan Wavefront™ aberrometer (VISX, Santa Clara, CA, USA). High and low contrast log MAR visual acuity and contrast sensitivity function (CSF) were also measured under photopic and mesopic conditions (OPTEC 6500 Vision Tester®). All measurements were conducted monocularly with an undilated pupil. **Results**: The RMS mean values for total HOA with SDD contact lenses were significantly lower than those at with unaided eyes ($p<0.001$) and a reduction for SA in the SDD was close to the baseline SA (zero μm) ($p<0.001$). For the SDD lens, there was a statistically significant correlation between the changes in the total HOA and the contact lens power ($r=0.237$, $p=0.018$) as well as between the changes in SA and the lens power ($r=0.324$, $p=0.001$). High contrast visual acuity (HCVA) and low contrast visual acuity (LCVA) with SDD lenses were -0.063 ± 0.062 and 0.119 ± 0.060, respectively under photopic and -0.003 ± 0.063 and 0.198 ± 0.067, respectively under mesopic condition. Contrast Sensitivity Function (CSF) with SDD lenses under both photopic and mesopic conditions was 3.095 ± 0.068 and 3.087 ± 0.074, respectively. **Conclusions**: The SDD contact lens designed to control SA reduced the total ocular HOA and SA of the eye, resulting in compensating for positive SA of the eyes. Thus, the optical benefits of the lens with SA control would be adopted for improving the quality of vision.

Key words: Ocular higher order aberrations, Spherical aberration, Aspheric soft contact lens

INTRODUCTION

The major goal of refractive correction is to achieve and maintain good visual function without the degradation of retinal image quality. In recent years, with the advancement in wavefront technology and the availability of diagnostic instruments, the interest of researchers or practitioners has been concentrated on correcting ocular aberrations to improve the quality of vision after correcting spherical and astigmatic refractive errors.[1,2] It has been found that correction of higher order aberrations (HOA) improves visual performance in theory[3] and in practice.[4,5] The advances have already been adopted in refractive surgery and intraocular lenses as a means for correcting monochromatic HOA in a clinical environment.

In the case of contact lenses, considering the possibility of improving visual quality by correcting ocular aberrations, contact lens manufacturers have applied aspheric optics to the design of soft contact lenses in order to reduce HOA, mainly spherical aberration (SA).[6,7] The adaptation of rotationally symmetrical contact lenses for correcting HOA is limited to SA which is by definition rotationally symmetric,[8] as it is difficult to have a fixed direction except for SA in all HOA.[9] The application is based on optical theory that certain aspheric design generates negative SA in the contact lens to compensate for average positive SA exist-

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ing in the population.[10] If correcting SA is possible with this specific type of aspheric soft contact lens designs, it is postulated that this type of aspheric lens design is better than conventional spherical design for improving quality of vision. The aim of this study was to assess the aspheric soft contact lenses designed to reduce SA on total ocular HOA and SA, and its effect on the high and low contrast visual acuity and contrast sensitivity function.

METHODS

1. Subjects

Subjects were recruited from the regular contact lens wearers who had visited the contact lens clinic. Fifty subjects (wearing period: 29 months, range 12 to 66 months) who met no more than 0.50D of refractive cylinder were enrolled in the study. They also agreed to wear the new lens for at least 8 hours per day during this study period. Best-corrected monocular visual acuity of 20/20 or better with both contact lenses and spectacles was observed in each eye for all subjects. None of the subjects had any ocular diseases, or any contraindication for soft contact lens wear. The demographics and biometric data of the 100 eyes are listed in Table 1.

All subjects received the detailed explanations of this study and signed an informed consent document prior to data collection.

Table 1. Subjects' demographics and biometric data

	Mean ± SD (range)
Number	50 (100 eyes)
Sex (M, F)	13, 37
Age (years)	25.5 ± 5.8 (17 ~ 39)
Sphere(D)	−4.10 ± 1.67 (−1.50 ~ −8.00)
Cylinder(D)	−0.11 ± 0.18 (0.00 ~ −0.50)
SE(D)	−4.15 ± 1.67 (−1.50 ~ −7.50)
Flat K(mm)	7.86 ± 0.19 (7.37 ~ 8.30)
Steep K(mm)	7.71 ± 0.19 (7.24 ~ 8.15)
Pupil size (mm)	4.58 ± 0.08 (2.60 ~6.20)

SE, spherical equivalent; K, keratometry.

2. Materials and method

1) Contact lens

Aspheric soft contact lenses [Soflens Daily Disposable: SDD), B+L Incorporated, Rochester, NY, USA] were used for the study. Details of these lenses are listed in Table 2.

Table 2. Parameters of available SDD soft contact lens

	Soft contact lens
Name	Soflens Daily Disposable
Design	Anterior surface aspheric
Manufacturer	Bausch+ Lomb Inc.
Material	Hilafilcon B
Water content (%)	59
FDA classification	Group II
Base curve (mm)	8.6
Diameter (mm)	14.2
Method of manufacture	Cast molding

FDA, Food and Drug Administration (USA).

According to Bausch+Lomb, the aspheric anterior surface of SDD is designed to reduce for SA (+0.15 μm) of an average eye by adjusting the amount of asphericity of the anterior lens surface for each lens power (the lens has incorporated a negative SA of −0.15 μm for a 6 mm optical zone diameter).[11]

2) Experimental procedure

This study involved two visits. In the first visit, all subjects underwent a slit-lamp inspection and an initial optometric examination to determine optimal lens power and base curve. Visual acuity was taken with best spectacle-corrected visual acuity using spectacle trial lenses and then wavefront aberration were measured with their own spherical contact lenses on and for the unaided eyes. After the ocular measures, the subjects were fitted with Soflens daily disposable (SDD) contact lenses and all subjects wearing the contact lenses were examined for acceptable movement, contration and comfort with a slit lamp. The SDD lenses were dispensed to each subject. The subjects were instructed to wear the SDD lenses. After wearing the SDD lenses for 15 days, all subjects came back in the morning and underwent a slit-lamp re-examination followed by high and low contrast log MAR visual acuity, and ocular aberrations with the SDD lens wear using the same procedure as the first visit. Lastly, contrast sensitivity was measured with the SDD wear. At each visit, all measurements were carried out monocularly with an undilated pupil. All measurements and contact lens fitting were performed by the same practitioner. The subjects were instructed to halt their own conventional soft contact lens wear at least one day before the experimental period commenced.

3) Visual acuity measurement

Visual acuity was measured monocularly under photopic and mesopic conditions with the best spherical power correction, using a high (100%) and low (20%)-contrast ETDRS acuity charts. The testing distance was 4 m and visual acuity score was recorded using log MAR units. The test ended when subjects were read incorrectly in twice. The illumination at the eye plane for high contrast visual acuity (HCVA) and low contrast visual acuity (LCVA) under photopic and mesopic lighting conditions was 200 and 22 lux, respectively (Digital Light Meter, TES-1330A, Taiwan).

4) Measurement of contrast sensitivity function

Contrast sensitivity Function (CSF) was measured monocularly first under photopic (85.0 cd/m^2) and then under mesopic (3.0 cd/m^2) conditions without additional glare light using the OPTEC 6500 Vision Tester® (Stereo Optical Co., Inc., Chicago, USA) including EyeView®Functional Vision Analysis Software. Each subject was examined with five spatial frequencies (1.5, 3, 6, 12 and 18 cycles per degree) and nine contrast levels, starting with the lowest spatial frequency (1.5 cpd). Log CSF for each stimulus was calculated. Integral log CSF values proposed by Mannos and Sakrison,[12] which were calculated from the five spatial frequencies obtained with the sine-wave grating charts, were used for the analysis.

5) Wavefront aberration measurement

Ocular aberrations were measured using Wave-Scan Wavefront™ aberrometer (VISX, Santa Clara, CA, USA) with a Hartmann-shark wave-sensor. This aberrometer measures low and high-order aberrations, capturing readings for Zernike coefficients up to the sixth order.[13] In this study, total HOA and stand alone SA for a 4-mm pupil size were measured. In order to maximize the influence of pupil size, ocular aberration measurement was performed in a dark room.

Pupil size was determined under photopic conditions (190 lux) with a natural pupil using ORB-ScanII (Bausch + Lomb, Rochester, NY), where a pupillometry function is incorporated within the topographer.

6) Statistical analysis

Comparisons between the SDD and the unaided eyes were analyzed using the Paired student t-test. Total HOA was done for root mean square (RMS) value. Analysis of variance (ANOVA) was used for the comparisons among the lens power subgroups with the mean of the change in SA. Pearson correlation test was analyzed for correlation between ocular aberrations and refractive error in SDD lens designs or the unaided eyes. Origin 6.0 program (OriginLab Co., Northampton, USA) was used for statistical analysis. Differences were considered statistically significant when p values were < 0.05.

RESULTS AND DISCUSSION

Results of the total HOA and SA with unaided eyes and the SDD lenses on the eyes are given in Table 3.

The RMS mean value for total HOA with SDD contact lens (0.327±0.126 μm) was significantly lower than that with unaided eyes (0.387±0.136 μm) (t=8.117, p<0.001) and the mean value for SA was lower with the SDD lens (0.002±0.073 μm) than that with unaided eyes (0.179± 0.097 μm) (t=23.892, p<0.001) (Fig. 1). Those HOA and SA values were significantly lower (t=7.301, p<0.001) compared with spherical lenses (0.366±0.125 μm and 0.040± 0.096 μm, respectively), (unpublished our data).

All subjects in this study showed positive ocular SA in the unaided eyes and this is consistent with previous findings.[14,15] The level of positive SA was demonstrated to be significantly higher for unaided eyes compared to the eyes with SDD lens wear.[16,17] Given that optical aberrations in the eyes with contact lenses have considerably individual variations,[18-23] the effect of correcting ocular SA with aspheric contact lenses may rely on the subject's baseline aberrations. In our results, it has been clearly shown that wearing SDD lenses considerably reduced the lens wearers' baseline ocular SA. The mean SA observed in the

Table 3. Total higher order aberrations and spherical aberration with unaided eyes and with the SDD soft contact lenses

N=100	HOA (RMS) (μm)	SA (Z_4^0) (μm)
SDD lens	0.327±0.126[a]	0.002±0.073
Unaided condition	0.387±0.136	0.179±0.097
p-value[b]	p<0.001	p<0.001

[a]Mean±standard deviation; RMS, root mean square; HOA, higher order aberrations; SA, spherical aberration; p-value[b], by paired t-test.

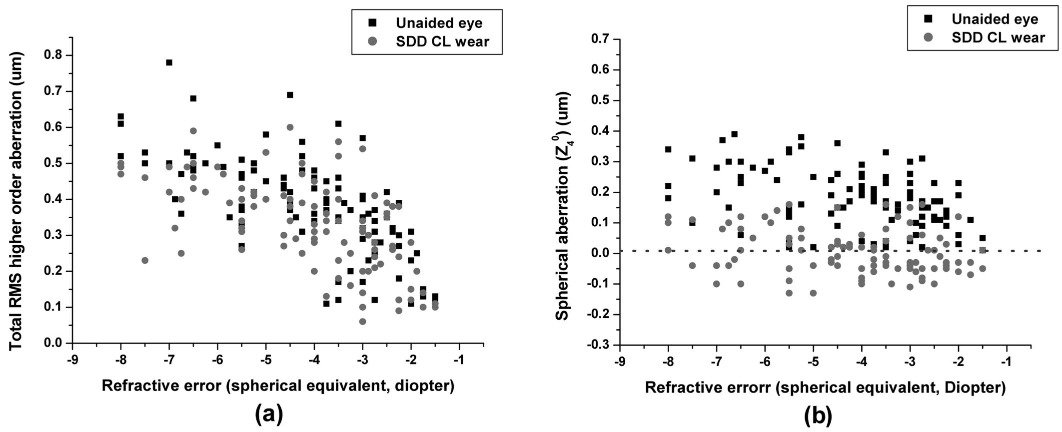

Fig. 1. Scattergrams of wavefront aberration as functions of spherical equivalent refractive error. (a) Total root mean square (RMS) higher order aberrations for the unaided eye and wearing SDD soft contact lenses. (b) Z_4^0 zernike coefficient representing spherical aberration for the unaided eye and wearing SDD soft contact lenses.

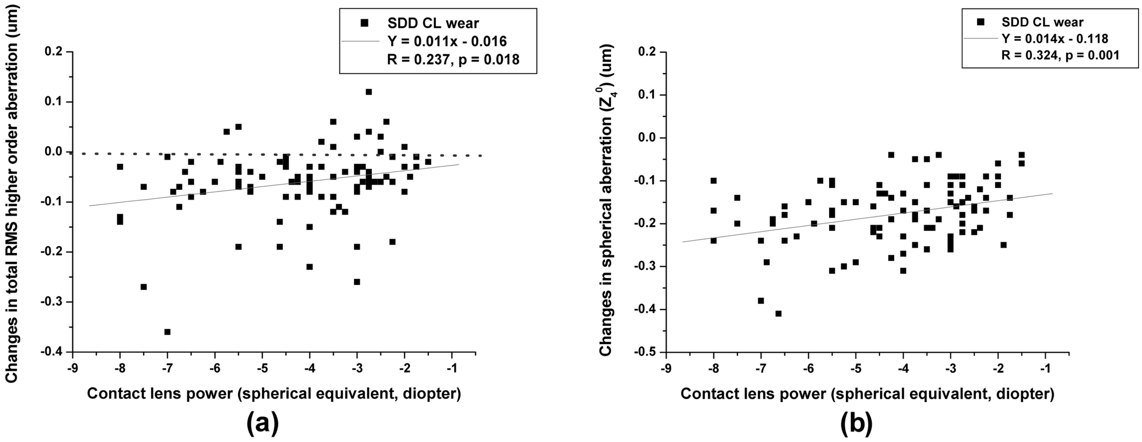

Fig. 2. Effect of SDD soft contact lens power on the change in total higher order aberrations and spherical aberration. (a) Changes in total higher order aberrations from the unaided eye versus contact lens power for SDD contact lens wearers. (b) Changes in spherical aberration from the unaided eye versus contact lens power for SDD contact lens wearers.

SDD lenses is essentially near to zero and has a narrower standard deviation. In the relationship between ocular aberrations and refractive error, statistically significant correlation was found between the amount of total HOA in unaided eye and spherical equivalent refractive error ($r=-0.676$, $p<0.001$). There was also significant correlation between the amount of SA in unaided eye and spherical equivalent refractive error ($r=-0.419$, $p<0.001$). The correlation between ocular aberration and refractive error in this study is in accordance with previous studies.[15] Our findings are explained that the higher HOA and SA the eye has, the higher refractive error it has.[24,25]

The mean±standard deviation of the changes in HOA and SA between the unaided eyes and the eyes with the SDD lens was -0.060 ± 0.074 and -0.178 ± 0.074, respectively. There was statistically significant correlation between total HOA and refractive error in the unaided eyes ($r=-0.676$, $p<0.001$). The relationship between refractive error and SA of the unaided eyes was also significant correlation ($r=-0.419$, $p<0.001$). The effect of SDD lens power on the change in total HOA and SA is shown in Fig. 2. For the SDD lens, there was a statistically significant correlation between the changes in the total HOA and the contact lens power ($r=0.237$, $p=0.018$) as well as between the changes in SA and the lens power ($r=0.324$, $p= 0.001$).

The mean±standard deviation of the change in SA from the unaided eyes to the eyes with the SDD lens with respect to high, moderate and low lens power subgroups is shown in Table 4.

This study tried to calculate the amount of SA of the SDD itself by calculating SA changes induced by the SDD. In other words, the SA value for the lens was calcu-

Table 4. Changes in spherical aberration from the unaided eyes to the eyes with the SDD by high, moderate and low power lenses

N = 100	SA (Z_4^0) (μm)			
	Low power (D)	Moderate power (D)	High power (D)	p-value[b]
	−1.50 to −3.00(n=35)	−3.25 to −5.75(n=50)	−6.00 to −8.00(n=15)	
Unaided eye	0.138 ± 0.078	0.186 ± 0.097	0.248 ± 0.092	0.0004
with SDD lens	−0.013 ± 0.068	0.004 ± 0.075	0.027 ± 0.077	0.174
Changes in SA	−0.151 ± 0.059[a]	−0.182 ± 0.074	−0.221 ± 0.084	0.006

[a]Mean±standard deviation; SA, spherical aberration; p-value[b], by ANOVA test.

lated by subtracting the SA value of the lens on the eye from the SA value for the unaided eye. For the SA changes with the SDD powers, the SDD lenses were categorized by the lens power into three groups such as high, moderate and low myopic power subgroups.

For unaided eye, the low power group was 0.138±0.078 and the mean values of moderate and high power groups were 0.186±0.097 and 0.248±0.092, respectively. The low lens power group in SDD lens was −0.013±0.068 and the mean values of moderate and high power lens groups in SDD lens were 0.004±0.075 and 0.027±0.077, respectively. The difference in unaided eye power subgroups was statistically significant (F=8.362, p=0.0004). As expected, there was no statistically significant among the three subgroups with the SDD lens wear (F=1.782, p=0.174).

The SA changes with the low power SDD group were −0.151±0.059 and the mean values of moderate and high power lens groups were −0.182±0.074 and −0.221±0.084, respectively. The difference of change in SA among the lens power subgroups was statistically significant (F=5.334, p=0.006). SA has significantly more negative reduction in the moderate and high power subgroups than in the low power subgroup.

In fact, previous studies[26,27] have shown that it is not clear what effect aspheric lenses have on SA on individual variations, since these lenses have depended on the assumption that most subjects have the same amount of SA. Thus, our results imply that the SDD contact lens have been designed to control the average amount of SA for each power of the lenses. These findings suggest that mass-produced lenses (non-custom-made aspheric lenses controlled SA) could be feasible as a practical method for correcting SA, although the benefit is contingent upon the baseline level of individual ocular SA[21,23] and pupil size.[28,29]

The mean values of high contrast and low contrast log MAR visual acuity under photopic condition were −0.063 ±0.062 and 0.119±0.060, respectively, and −0.003±0.063 and 0.198±0.067, respectively under mesopic condition. Integral mean value calculated with log CSF data for the SDD lens was 3.095±0.068 in photopic conditions and was 3.087±0.074 in mesopic conditions. In the current study, we confirmed the hypothesis that incorporating negative SA into a contact lens may reduce ocular aberrations.[6,30] Previous studies noted that the amount of SA caused by contact lens wear, which contributes substantially to HOA,[31,32] was correlated with visual quality.[33-35] Our study showed that eyes with negative SA induced by the contact lens resulted in significantly better HCVA, LCVA and CSF. These findings somewhat correspond with previous studies[36-38] in which it was observed that negative SA induced by contact lenses resulted in less impaired effect on contrast sensitivity or visual acuity than positive SA. Cox et al.[36] noticed that positive SA resulted in significantly worse contrast sensitivity than equivalent negative SA.

In recent years, it is widely accepted in clinical practice that contrast sensitivity or low contrast visual acuity testing has been used to determine the quality of vision regarding visual performance.[39,40] Pesudovs et al.[41] noticed that LCVA under mesopic conditions was significantly affected by ocular HOA. This is explained by the fact that the effect of ocular aberrations on visual quality depends on pupil size[28,29] and it would be related to low contrast conditions or low illumination conditions.[16,36] De Brabander et al.[30] suggested that elective manipulation of SA in individuals could be better improvement in contrast sensitivity, especially in soft contact lenses with high power. It is shown by the fact that contrast sensitivity in mesopic conditions has been received as a key factor to assess subtle changes and difference in visual quality.[42,43] Dietze et al.[8] suggested that visual benefits could be limited by coma arising from designs and imperfect centration of an aspheric contact lens on the eye. Therefore, understanding the interaction of other aberrations with the eye wearing contact lens could be useful in optimizing contact lens designs for correcting ocular aberrations. Further study is needed to compare the visual performance of aspheric soft contact lenses designed to reduce spherical aberration of the eye and spherical soft contact lenses to evaluate the quality of vision.

CONCLUSIONS

In this study, we have shown that the SDD soft contact lens design used in this study reduced the total ocular HOA and SA of the eye, resulting in better HCVA and LCVA as well as CSF under both photopic and mesopic conditions. The results of this study suggest that the optical benefits of aspheric soft contact lenses with SA control would be adopted for improving the quality of vision. Especially, the SDD soft lens might be greater for the average population who has positive SA of the eye or larger pupil size under mesopic conditions.

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비구면 소프트콘택트렌즈 착용에 의한 눈의 구면수차 변화

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목적: 구면수차를 감소시키기 위해 설계된 비구면 소프트콘택트렌즈를 착용시킨 후 눈에서 변화된 고위수차와 구면수차를 분석하였다. **방법**: 50명의 소프트 콘택트렌즈 착용자가 연구에 참여하였으며 SDD(Soflens Daily Disposable, Bausch+Lomb) 비구면 렌즈를 착용시킨 후 Wave-Scan Wavefront™ aberrometer (VISX, Santa Clara, CA, USA)를 이용하여 눈 전체의 고위수차와 구면수차를 4 mm의 동공크기를 기준으로 측정하였고, 구면수차 변화량은 착용한 비구면 렌즈의 약도, 중도, 고도의 도수에 따라 비교, 분석하였다. 밝은 조명(photopic)과 어두운(mesopic) 조명상태에서 대비도를 가지는 시력표(100%와 20%)를 이용하여 시력 검사를 하였고 OPTEC 6500 Vision Tester®(Stereo Optical Co., Inc., Chicago, USA)를 사용하여 밝은 조명(photopic)과 어두운(mesopic)조명 상태의 대비감도를 각각 측정하였다. 모든 측정은 산동 시키지 않은 상태에서 단안으로 시행하였다. **결과**: SDD 비구면 렌즈를 착용한 경우 눈의 전체고위수차는 나안 상태보다 유의하게 감소하였고($p<0.001$), 구면수차는 상당히 감소하여 0에 근접하는 경향을 보였다($p<0.001$). SDD 렌즈 도수에 따라 전체고위수차 변화량($r=0.237$, $p=0.018$)과 구면수차 변화량($r=0.324$, $p=0.001$)은 유의한 상관관계가 나타났다. 밝은 조명상태에서 100% 및 20% 대비도 시력은 각각 -0.063 ± 0.062와 0.119 ± 0.060으로 나타났고, 어두운 조명상태에서 100% 및 20% 대비도 시력은 -0.003 ± 0.063과 0.198 ± 0.067으로 측정되었다. 밝은 조명상태와 어두운 조명상태에서 대비감도는 각각 3.095 ± 0.068과 3.087 ± 0.074로 나타났다. **결론**: 구면수차를 제어한 비구면 디자인의 소프렌 소프트렌즈(SDD)는 눈의 전체 고위수차와 구면수차를 감소시키고 눈의 구면수차를 보정하면서 시력의 질을 향상시킬 수 있을 것으로 사료된다.

주제어: 고위수차, 구면수차, 비구면 소프트콘택트렌즈