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Efficacy of spherical aberration correction based on contact lens power☆

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ABSTRACT

Purpose: To investigate the efficacy of spherical aberration (SA) correction with aspheric contact lenses (aspheric lenses) based on lens power, and compare the results with those of spherical contact lenses (spherical lenses).
Methods: Ocular higher-order aberrations were measured with a wavefront sensor, in 11 myopic subjects wearing an aspheric lens (Medalist Fresh fit (PUREVISION 2 HD); Bausch + Lomb) or a spherical lens (ACUVUE Oasys; Johnson & Johnson). Six different lens powers (−7.00 diopters (D), −5.00 D, −3.00 D, −1.00 D, +1.00 D, +3.00 D) were used for all subjects. The amount of SA correction from the contact lens at each power was calculated as the difference between SA with the contact lens on-eye and SA of the eye alone.
Results: For the spherical lenses, SA correction was close to 0.00 μm for the +1.00 D lens, became more positive as the labeled lens power increased and became more negative as the labeled lens power decreased. For the aspheric lenses, SA correction was consistent, from −0.15 to −0.05 μm, for all lens powers except for the −1.00 D lens. SA correction for the spherical and aspheric lenses was significantly different at −7.00 D ($p = 0.040$), −3.00 D ($p = 0.015$), −1.00 D ($p < 0.001$), +1.00 D ($p = 0.006$), and +3.00 D ($p < 0.001$) powers.
Conclusion: An aspheric lens is capable of correcting SA at different lens powers, and has SA correction in the range of −0.15 to −0.05 μm over a 6 mm aperture.

1. Introduction

Recent advances in wavefront technology have enabled us to evaluate optical quality [1]. In addition to refractive error, irregular astigmatism and higher-order aberrations (HOAs) of the entire eye can be determined quantitatively with wavefront analysis. Wavefront measurements also have been used to evaluate the optical quality of eyes while wearing contact lenses. Many of the studies reporting optical quality in eyes while wearing contact lenses use a wavefront sensor, but mostly focus on differences in lens materials or lens designs.

Recently, there have been a number of studies reporting potential advantages of wavefront correction with contact lenses. Several studies have reported the efficacy of custom-made contact lenses [2–4]. Today, several manufacturers have developed commercially available aspheric-design soft contact lenses (SCLs) to correct spherical aberration (SA) as a means of partially correcting HOAs. SA is one of the important HOA components, and accounts for 20–40% of HOAs when the pupil is large [5–8]. Since contact lenses may rotate on the ocular surface and may cause asymmetrical components of HOAs, such as coma, to increase, designing aspheric contact lenses to correct SA in a rotationally symmetric fashion is a sensible approach [2]. The efficacy of aspheric-design SCL for SA correction has been reported through previous research [9–11]. For standard spherical-design SCL, negative SA increases with increasing negative power [12]. However, little is known about the efficacy of aspheric-design SCL across a range of contact lens powers.

The aim of the current study is to investigate the efficacy of SA correction with aspheric-design SCL across a range of contact lens powers, and compare the results with those of spherical-design SCL. Specifically, we are interested in exploring the relationship between SA in eyes with spherical and aspheric contact lenses of different lens powers.

☆ Contact lenses used in the current study were provided by Bausch + Lomb, Tokyo, Japan. None of the other authors or their family members has a proprietary or financial interest in any of the materials or instruments mentioned in this article.

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2. Methods

The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation, which adhered to the tenets of the Declaration of Helsinki. All patients provided informed consent after receiving an explanation of the nature and possible consequences of the study.

2.1. Subjects

Twenty-two eyes of 11 normal volunteers (7 men, 4 women; average age, 33.5 ± 7.5 years) participated in this study. All participants met the following criteria: (1) refractive error between +2.00 and −8.00 diopters (D); (2) astigmatism less than 1.50 D; (3) age older than 20; (4) no ocular pathology or systemic disorders; (5) not taking any drugs with known effect on visual acuity or accommodation; and (6) best corrected visual acuity of 20/20 or better.

2.2. Types of soft contact lenses

Balafilcon A lenses (Medalist Fresh fit (PUREVISION 2 HD); Bausch + Lomb, Tokyo, Japan) (aspheric lenses) and senofilcon A lenses (ACUVUE Oasys; Johnson & Johnson K.K. Vision Care Company, Tokyo, Japan) (spherical lenses) were compared. Details of both products are shown in Table 1. Six different lens powers (−7.00 D, −5.00 D, −3.00 D, −1.00 D, +1.00 D, +3.00 D) were used for all subjects.

2.3. Experimental protocol

Wavefront aberrations were measured in each eye for the following conditions: at baseline without a contact lens and with soft contact lenses of six different combinations of designs and powers for both eyes (Table 2). Each subject's eye was examined first without a contact lens. After inserting each contact lens, the lens was assessed to confirm a proper fit to the eye. Wavefront aberrations were measured after the lens settled on-eye for at least 10 min following insertion. This contact lens insertion and wavefront measurement procedure was repeated six times with different contact lens designs and powers.

Table 1
Details of the soft contact lenses used in this study.

	Aspheric lens	Spherical lens
Name (Japan)	Medalist Fresh fit	ACUVUE Oasys
Name (UK)	PUREVISION 2 HD	ACUVUE Oasys
Manufacturer	Bausch + Lomb	Johnson & Johnson
Material	Balafilcon A	Senofilcon A
FDA classification	Group III	Group I
Water content	36.0%	38.0%
Base curve (mm)	8.6 mm	8.8 mm
Diameter (mm)	14.0 mm	14.0 mm
Center thickness (mm)	0.07 mm (−3.00 D)	0.07 mm (−3.00 D)
Method of manufacture	Fully cast molded	Fully cast molded

D, diopters.

Table 2
Wavefront measurement order and condition.

Measurement order	Right eye	Left eye
1	Unaided	Unaided
2	−5.00 D aspheric lens	−7.00 D aspheric lens
3	−5.00 D spherical lens	−7.00 D spherical lens
4	−3.00 D aspheric lens	−1.00 D aspheric lens
5	−3.00 D spherical lens	−1.00 D spherical lens
6	+3.00 D aspheric lens	+1.00 D aspheric lens
7	+3.00 D spherical lens	+1.00 D spherical lens

D, diopters.

2.4. Measurement of wavefront aberrations

Measurements of the ocular wavefront aberrations were performed using the KR-1W (Topcon, Tokyo, Japan) instrument. To obtain appropriate wavefront measurements through large pupils, the subjects' pupils were dilated with a mixture of 0.5% phenylephrine and 0.5% tropicamide (Mydrin P; Santen Pharmaceutical Co., Osaka, Japan). Measurements were taken when the pupil was greater than 6 mm, at least 30 min after the pupil began dilating.

The acquired wavefront data were analyzed quantitatively for photopic vision (central 4 mm diameter) and for scotopic vision (central 6 mm diameter) up to the sixth order by expanding the set of Zernike polynomials. For each pair of standard Zernike terms for trefoil, coma, tetrafoil and secondary astigmatism, one value for the magnitude was calculated by Zernike vector analysis [13–15]. The SA was expressed as a positive or negative value, not as an absolute value. The amount of SA correction from the contact lens at each power was calculated as the difference between SA with a contact lens on-eye and SA of the eye alone.

2.5. Statistical analysis

The data were analyzed using statistical analysis software StatView 5.0 (Systat Software, Inc., Chicago, IL). Paired-tests were used for the comparison of the amount of residual SA between the lenses at each lens power. Pearson's correlation coefficients were calculated to explore the correlation between SA and lens power, for each lens. $p < 0.05$ was considered significant for all analyses.

3. Results

Fig. 1 shows color-coded maps of SA over a 6 mm diameter for a subject with no lens in place, a spherical contact lens and an aspheric contact lens. In comparison to the aspheric lens, color-coded maps of SA with the spherical lens showed an advance of light (warm color) in the central part, indicating positive SA for both the −1.00 D and +3.00 D lenses. The +3.00 D lens indicated more positive SA than the −1.00 D lens (Fig. 1, top middle, and bottom middle). Fewer alterations in the central part of the cornea were found in the color-coded map with the aspheric lens on-eye (Fig. 1, top right, and bottom right).

SA values calculated from the data obtained from 11 subjects with the lenses in place are shown in Fig. 2. Regression lines to fit SA data with each lens are also shown. Without contact lenses on-eye, the mean SA of the subjects' eye was 0.018 ± 0.033 μm for the 4 mm pupils and 0.122 ± 0.109 μm for the 6 mm pupils. With the spherical lenses, positive SA increased when the lenses were less minus power than −5.00 D, and negative SA increased when the lens power was more minus than −5.00 D. This tendency was more noticeable in the 6 mm pupils than in the 4 mm pupils. For SA values in a 6 mm pupil, there was a moderate positive correlation between SA and lens power in spherical lenses ($R = 0.625$, $p < 0.001$), while there was no correlation between SA and lens power in aspheric lenses ($R = 0.176$, $p = 0.158$). Mean residual SA values calculated in the 6 mm pupils from the data obtained with the two contact lenses are shown in Fig. 3. SA correction of the spherical lenses was close to 0.00 μm at +1.00 D, and positive SA correction increased with the increase in the plus lens powers. Negative SA correction increased with increases in the minus lens powers from +1.00 D. In contrast, the mean residual SA with the aspheric lenses is much closer to zero for all lens powers because the magnitude of SA in the aspheric lenses is stable, from −0.15 to −0.05 μm, across all measured lens powers except for −1.00 D. Residual SA