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ZERNIKE ASTIGMATISM AND VISUAL PERFORMANCE IN MYOPIC EYES BY RIGID GAS PERMEABLE CONTACT LENSES WEAR

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Purpose: To investigate the effects of rigid-gas-permeable contact lens (RGP-CL) wear on Zernike astigmatism and visual performance in myopic eyes. **Methods:** A wavefront sensor was used to evaluate Zernike astigmatism for 21 eyes with minimum astigmatism and 18 eyes with moderate astigmatism under three different modes of refractive correction: the RGP-CL, spectacle lens correcting spherical equivalent (SL) and spectacle lens fully correcting spherical error and astigmatism (fSL). Contrast visual acuity was assessed with a VA tester at four contrast levels and two luminance backgrounds. **Results:** Compared to the SL wear, RGP-CL wear changed the main axis astigmatism (Z_2^2) from -0.09 ± 0.34 to 0.34 ± 0.22 for the minimum astigmatism group, while the contrast VA was improved about 0.05 LogMAR ($F = 8.06$, $p < 0.01$). For the group with moderate astigmatism, significant reduction in Z_2^2 was found for both fSL wear ($t = 4.78$, $p < 0.001$) and RGP-CL wear ($t = 6.29$, $p < 0.0001$). The changes in astigmatism were significantly correlated between the fSL and RGP-CL wears ($r = 0.897$, $p < 0.0001$ for Z_2^{-2}; and $r = 0.643$, $p = 0.004$ for Z_2^2). Contrast VA was significantly improved for both fSL and RGP-CL wears and the improvements were significantly correlated between each other for all four contrast levels and two backgrounds. **Conclusion:** RGP-CL wear induces astigmatism for the eyes with minor astigmatism probably due to a correction of corneal astigmatism and thus a manifesting of the lens astigmatism. For the astigmatic eyes, RGP-CL wear has similar effect on correcting astigmatism as the spectacle lens wear with spherical-cylinder correction and also produces similar visual improvement.

Keywords: Wavefront aberration; Zernike aberration; contrast visual acuity; rigid-gas-permeable contact lens; spectacle lens.

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1. Introduction

It has been recently demonstrated with wavefront technique that second-order wavefront aberrations, mainly the astigmatism terms, were reduced in the myopic eyes when rigid-gas-permeable contact lens (RGP-CL) was worn.[1–3] This was attributed to a molding effect of the rotationally symmetrical RGP-CL on the asymmetrical corneal surface, which corrects corneal astigmatism. Recent studies on the sources of ocular wavefront aberrations have shown that there is a process of aberration compensation between the cornea and the lens for many Zernike aberrations.[4–6] For example, the positive corneal spherical aberration is well compensated by the negative spherical aberration in the crystalline lens. This type of aberration compensation was also demonstrated for Zernike astigmatism in young eyes.[4,5] Because of the existence of the aberration compensation between the cornea and the lens, astigmatism in the whole eye is therefore determined not only by the cornea but also by the lens and its interaction with the cornea. Since the RGP-CL is supposed to create a tear reservoir to mask corneal astigmatism, the question is how the whole eye astigmatism was overall reduced when RGP-CL was worn. It may be also interesting to know how the astigmatism correction by RGP-CL wear is comparable to spectacle lens correction.

On the other hand, it is expected that visual performance for the eyes wearing RGP-CL would be improved because of the correction of astigmatism. But, no agreement on visual improvement has been reached yet in previous studies.[7–11] In order to better understand the changes in both astigmatism and visual performance for the eyes with RGP-CL, this study was designed to measure both wavefront aberration and contrast visual acuity (CVA) for a group of young myopes wearing RGP-CL, and the changes in astigmatism and visual acuity were compared to those for spectacle lens wear.

2. Methods

2.1. *Subjects*

21 subjects aged from 21 to 32 years old (mean = 26.2 years) participated in the study. Both right and left eyes of the subjects were tested, but three out of the 42 eyes was excluded from data analysis because the pupil size was smaller than 6.0 mm during aberration measurement. Spherical refractive error of the subjects ranged from −1.75D to −8.25D with a mean of -4.81 ± 1.89D. Of the 39 eyes, 21 had minimum astigmatism (less than 0.25DC) and 18 had moderate astigmatism ranged from −0.50DC to −1.50DC with a mean of -1.00 ± 0.36D. Monocular best corrected distance visual acuity was better than 20/20, and all subjects were free of ocular disease. Informed consent was obtained from all subjects before their participation in the study after the nature and possible consequences of the study had been explained to them. The study had approval from Wenzhou Medical College Research Ethics Committee and complied with the tenets of the Declaration of Helsinki.

2.2. *Instruments*

A wavefront sensor (WASCA, Carl Zeiss Meditec) was used to measure wavefront aberrations under condition with room lights off. The wavefront sensor directly provides a series of Zernike aberrations including the second-order astigmatism terms. Measurement of CVA was achieved using a multi-functional VA tester[12] (MFVA-100, BriteEye Medical Tech Co. Ltd, Shenzhen, China), which is capable of measuring distant VA by isolate letters under four different contrast levels (100%, 25%, 10% and 5%) and two different backgrounds (250 cd/m^2 and 25 cd/m^2).

2.3. *Procedure*

This was a three-visit clinical study, and refraction for each subject was made at the initial visit. For each subject, wavefront aberration and CVA were examined for three lens wear conditions: (1) spectacle lens (SL) corrected for spherical equivalent, (2) rigid-gas-permeable contact lens (RGP-CL, XO, Boston) corrected for spherical equivalent, and (3) spectacle lens (fSL) fully corrected for both spherical error and astigmatism. For the eyes with minimum astigmatism, fSL was not performed due to their minimum astigmatism. The three types of correction lenses were fitted by two experienced optometrists and optimum fitting was ascertained for each subject with each lens type. RGP-CL fitting is undertaken using trial lens fitting sets in a range of BOZRs (back optic zone radius) and TDs (total diameter). First, select a lens diameter based on corneal diameter, and select the BOZR based on the flattest keratometer reading, adjusting the BOZR and the TD depended on fluorescence pattern assessment. Then gain the prescription of RGP-CL by the result of over-refraction. Measurements were repeated three times for wavefront aberrations and twice for CVA. The order of measurements for correction lens types was the SL, fSL and then the RGP-CL. Measurement for RGP-CL condition was performed after one month of adaptation. For other correction lenses at least one hour of adaptation was used. An entire session of the tests for each subject took about over one month.

2.4. *Data analysis*

Data analysis was performed by separating the subjects into two groups: the group without astigmatism (<0.25DC) and the group with astigmatism. All statistical analyzes were carried out using SPSS 13.0. Difference in wavefront aberrations and CVA under the RGP-CL wear condition from the other correction conditions was statistically tested. Mean comparison in groups was conducted with single factor variance analysis, and Pearson correlations were used to determine the strength of the relationship.

3. Results

3.1. *Wavefront aberrations under different modes of refractive correction*

Figure 1 shows the mean-root-mean-square of total wavefront aberrations including the second-order astigmatisms and the higher-order aberrations from the third- up to seventh-order Zernike coefficients (tRMS, the solid bars) and the higher-order aberrations only (hRMS, the open bars) at a 6.0 mm pupil size for the 21 eyes with minimum astigmatism under two lens correction conditions (a) and the 18 eyes with moderate astigmatism under three lens correction conditions (b). There was no significant difference in tRMS or hRMS between the SL and RGP-CL correcting conditions for the group with minimum astigmatism ($P > 0.05$). But, significant differences between different modalities were found for either tRMS or hRMS between correcting conditions for the group with moderate astigmatism. Compared to the SL condition, tRMS value was significantly decreased for both RGP-CL wear ($t = 7.94$, $p < 0.0001$) and fSL correction ($t = 5.99$, $p < 0.0001$). The tRMS was significantly different between the RGP-CL and fSL conditions ($t = 2.21$, $p = 0.04$). For higher-order aberrations, as compared to the SL condition, the hRMS value was significantly decreased for RGP-CL wear ($t = 3.97$, $p < 0.001$), but not for the fSL condition ($P > 0.05$). There was a significant difference in hRMS between the RGP-CL and fSL conditions ($t = 4.8$, $p < 0.001$).

Table 1 summarizes the mean RMS values of the second-order astigmatism terms, mean oblique astigmatism (Z_2^{-2}) and mean main axis astigmatism (Z_2^2) at different correction modalities for the two groups. For the minimum astigmatism group, as shown in Table 1, no significant difference was found between the SL and RGP-CL conditions for either the mean RMS or the mean oblique

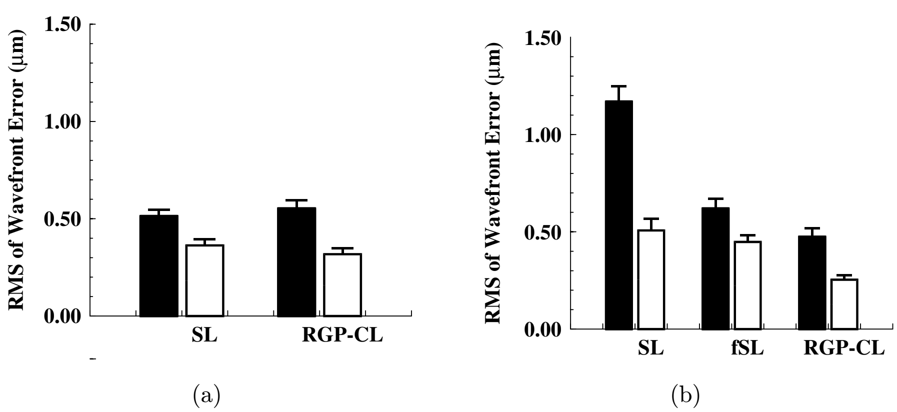


Fig. 1. Mean RMS of total wavefront aberrations (tRMS, the solid bars) and the higher-order aberrations only (hRMS, the open bars) at a 6.0 mm pupil size for 21 eyes with minimum astigmatism under SL and RGP-CL corrections (a) and 18 eyes with moderate astigmatism under SL, fSL, and RGP-CL corrections (b).

Table 1. Mean astigmatism (±SD) for the minimum astigmatism and moderate astigmatism groups under SL, fSL or RGP-CL correction conditions.

	Minimum astigmatism group		Moderate astigmatism group		
	SL	RGP-CL	SL	fSL	RGP-CL
RMS	0.38 ± 0.20	0.43 ± 0.20	1.04 ± 0.29	0.39 ± 0.25	0.38 ± 0.20
Z_2^{-2}	0.03 ± 0.26	0.03 ± 0.24	0.07 ± 0.59	0.09 ± 0.26	0.05 ± 0.26
Z_2^2	−0.09 ± 0.34	0.34 ± 0.22	−0.78 ± 0.47	−0.11 ± 0.36	0.08 ± 0.34

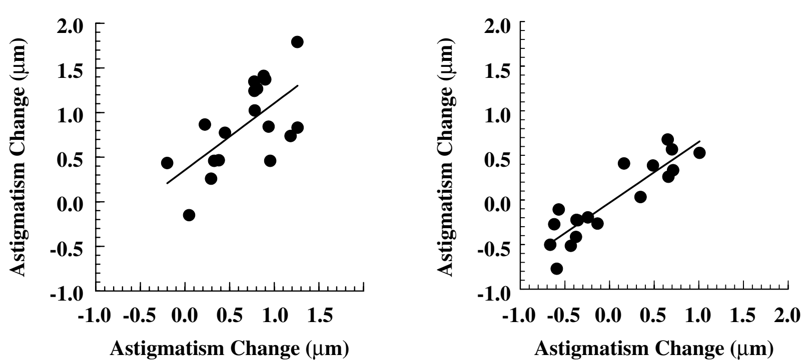
Note: SL, spectacle lens with spherical equivalent; RGP-CL, rigid-gas-permeable contact lens; fSL, spectacle lens with fully corrected for both spherical error and astigmatism.

astigmatism. But the main axis astigmatism was changed from negative to positive and also to a higher amplitude ($t = 4.93, p < 0.0001$). On the other hand, the mean RMS for the moderate astigmatism group was decreased in both fSL ($t = 7.15, p < 0.0001$) and RGP-CL ($t = 7.83$, $p < 0.0001$) conditions, as compared to the SL condition, but no difference was found between the fSL and RGP-CL conditions. There was not any significant change in mean oblique astigmatism between the three lens wear conditions. But the main axis astigmatism was reduced in fSL condition ($t = 4.78$, $p < 0.001$), as compared to the SL condition, and it was changed to positive from negative when RGP-CL was worn ($t = 6.29$, $p < 0.0001$). However, the difference in mean levels between the fSL and RGP-CL conditions was not significant ($t = 1.60$, $p = 0.13$).

In order to compare the effect of astigmatism correction between the RGP-CL and fSL conditions, correlation between the changes in the Zernike astigmatism terms, as compared to the SL condition, were tested for the group with moderate astigmatism. Figure 2 shows the correlation of the changes in oblique astigmatism (a) and main axis astigmatism (b) between the RGP-CL and fSL conditions. For either astigmatism term, the correlation was significant ($r = 0.897$, $p < 0.0001$ for the oblique astigmatism; and $r = 0.643$, $p = 0.004$ for the main-axis astigmatism).

3.2. *CVA under different modes of refractive correction*

Mean CVA values (±SD) across four contrast levels under different refractive corrections are illustrated in Table 2 for the group with minimum astigmatism and Table 3 for the moderate astigmatism group, where the results for two different luminance backgrounds are presented separately. CVA values in the group with minimum astigmatism for the RGP-CL wear were significantly better than those for the SL wear under either the photopic condition ($F = 8.06$, $p < 0.01$, with a mean improvement of 0.05 LogMAR) or the low luminance condition



(a) (b)

Fig. 2. Correlation of the changes in oblique astigmatism (a) and main axis astigmatism (b) between the RGP-CL and fSL corrections, as compared to the SL condition, for the group with moderate astigmatism (X-axis is fSL and Y-axis is RGP-CL).

Table 2. CVA (mean ± sd) in LogMAR for 18 myopic eyes with minimum astigmatism under different lens wear conditions.

	Contrast level (%)			
	100	25	10	5
Photopic conditions				
SL	-0.09 ± 0.08	0.08 ± 0.09	0.30 ± 0.10	0.48 ± 0.12
RGP-CL	-0.15 ± 0.07	0.03 ± 0.09	0.24 ± 0.14	0.46 ± 0.13
Low luminance conditions				
SL	0.03 ± 0.08	0.17 ± 0.12	0.37 ± 0.14	0.58 ± 0.17
RGP-CL	-0.07 ± 0.09	0.12 ± 0.08	0.31 ± 0.10	0.52 ± 0.13

Note: SL, spectacle lens with spherical error corrected; RGP-CL, rigid-gas-permeable contact lens.

Table 3. CVA (mean ± sd) in LogMAR for 18 myopic eyes under different lens wear conditions.

	Contrast level (%)			
	100	25	10	5
Photopic conditions				
SL	-0.00 ± 0.10	0.15 ± 0.12	0.35 ± 0.12	0.54 ± 0.15
fSL	-0.09 ± 0.07	0.05 ± 0.07	0.24 ± 0.10	0.41 ± 0.07
RGP-CL	-0.13 ± 0.08	0.02 ± 0.09	0.22 ± 0.11	0.45 ± 0.13
Low luminance conditions				
SL	0.11 ± 0.11	0.28 ± 0.13	0.43 ± 0.14	0.62 ± 0.14
fSL	0.00 ± 0.09	0.14 ± 0.08	0.29 ± 0.10	0.50 ± 0.09
RGP-CL	-0.03 ± 0.08	0.10 ± 0.08	0.26 ± 0.09	0.46 ± 0.12

Note: SL, spectacle lens with spherical error corrected; RGP-CL, rigid-gas-permeable contact lens; fSL, spectacle lens with fully corrected for both spherical error and astigmatism.

($F = 13.82$, $p < 0.001$, with a mean improvement of 0.07 LogMAR).

For the moderate astigmatism group, the contrast VA was also improved, as compared to the SL condition, when fSL ($F = 46.5$, $p < 0.0001$, with a mean improvement of 0.11 LogMAR) or RGP-CL ($F = 48.5$, $p < 0.0001$, with a mean improvement of 0.12 LogMAR) was worn at the photopic luminance condition. But, the difference in contrast VA between fSL and RGP-CL conditions was not significant. Under the low luminance condition, similar improvement in contrast VA was found, as compared to the SL condition, for the fSL condition ($F = 45.2$, $p < 0.0001$, improved 0.13 LogMAR) and for the RGP-CL condition ($F = 70.6$, $p < 0.0001$, improved 0.16 LogMAR). In this luminance condition, better contrast VA was found with the RGP-CL wear than the fSL wear ($F = 5.04$, $p = 0.03$) and the mean difference was 0.03 LogMAR.

Both fSL and RGP-CL wear resulted in significant improvement in contrast VA for the group with moderate astigmatism, as shown in Table 3. In order to test the relationship in the visual improvement between the two corrections, correlation of the contrast VA improvements, as relative to the SL condition, was examined between the fSL and RGP-CL conditions. Figure 3 shows the correlation of VA improvements between the fSL and RGP-CL conditions at the 100% contrast level under both photopic (a) and low luminance (b) conditions. The correlations were significant for both luminance conditions ($r = 0.73$, $p < 0.001$, for the photopic condition; $r = 0.60$, $p = 0.008$ for the low luminance condition). At different contrast levels, the correlations were all significant and with similar correlation coefficient (photopic condition: $r = 0.84$, $p < 0.0001$ for 25%, $r = 0.73$, $p < 0.001$ for 10% and $r = 0.52$, $p = 0.03$ for 5%, respectively;

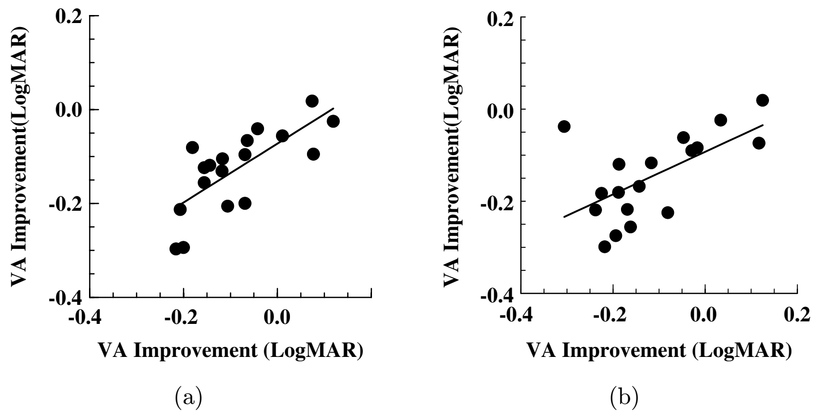


Fig. 3. Correlation of visual acuity improvements, relative to the SL condition, between the fSL and RGP-CL wears at 100% contrast level under photopic (a) and low luminance (b) conditions (X-axis is fSL and Y-axis is RGP-CL).

low luminance condition: $r = 0.56$, $p = 0.02$ for 25%, $r = 0.55$, $p = 0.02$ for 10% and $r = 0.51$, $p = 0.03$ for 5%, respectively).

4. Discussion

In one of our previous studies, we have showed a reduction of the second-order Zernike astigmatism for RGP-CL wear, and this was attributed to the molding effect of the RGP-CL on the corneal surface which reduced corneal astigmatism.[1–3] But the reduction of corneal astigmatism does not necessarily guarantee a decrease in astigmatism of the whole eye because the lens astigmatism will manifest its amplitude, but, of course, with an opposite sign, (e.g., becoming positive from negative), due to an original compensation of astigmatism between the cornea and the lens.[4,5] As a matter of fact, this was observed in this study as we separated our myopic eyes into two groups according to the level of baseline astigmatism. We found that the main axis astigmatism for the eyes with minimum astigmatism at original baseline was increased in amplitude and changed to opposite sign when RGP-CL was worn. This change in astigmatism could be explained by a manifest of the lens astigmatism which was compensated with the corneal astigmatism in original condition.

For the myopic eyes with moderate astigmatism, the main axis astigmatism was also changed from negative to positive when RGP-CL was worn. Although the sign change is similar as the minimum astigmatism group, the change in amplitude was much different. While the baseline astigmatism for the moderate astigmatism group was much higher than the minimum group, the resulted amplitude was less (Table 1). This result might suggest that corneal astigmatism in the group with moderate astigmatism was not completely compensated by the lens, probably due to a less amount of lens astigmatism. This might explain why the subjects in moderate group have higher level of baseline astigmatism than the minimum astigmatism group. But still, the moderate astigmatism group must also have greater amount of corneal astigmatism than the minimum astigmatism group because the amplitude of baseline astigmatism in moderate group was greater than the amplitude of the resulted astigmatism in minimum group. Therefore, corneal molding plays an important role in correcting astigmatism for astigmatic eyes with RGP-CL. In addition, the effect of astigmatism correction by RGP-CL for the astigmatic eyes is very similar to the fSL correction, as indicated by the high correlation of astigmatism changes between the fSL and RGP-CL wear (Fig. 2). So, an average reduction in second-order astigmatism with RGP-CL wear observed in our previous study was mainly due to a reduction dominated by the astigmatic eyes.

While the main axis astigmatism was slightly increased for the group with minimum astigmatism when RGP-CL was worn (Table 1), it did not show significant impact on CVA for our subjects. On the contrary, the contrast VA was improved about 0.05 LogMAR under photopic condition and 0.06 LogMAR under low luminance condition across the four contrast levels at the RGP-CL condition than at the SL condition (Table 2). This could be due to the fact that contact lens wear eliminates the minifying effect on the retinal image produced by the spectacle lens. The improvement was also found for the moderate astigmatism group when contrast visual acuities under low luminance condition for the RGP-CL wear were compared with the fSL condition. Previous studies have reported worse or similar visual performance when rigid contact lens was worn as compared to spectacle lens wear,[7–11] while the soft contact lens wear always produced worse visual performance.[13–17] The results in this study are not in agreement with the previous studies by showing visual improvement for RGP-CL wear relative to the SL wear. Further study to clarify the reason responsible for this inconsistency is desired.

Correction of astigmatism with fSL produced an improvement of visual acuity over one line for our moderate group compared with SL correction, and the increases were approximately parallel across the four contrast levels (Table 3). More increases were found for the RGP-CL wear as compared to SL correction. This suggests that the RGP-CL wear produced similar astigmatism correction as the fSL correction which resulted in comparable visual improvement. Significant correlations of the improvements of CVA between the fSL and RGP-CL wears (Fig. 3) further confirmed the role of RGP-CL in correcting astigmatism and improving visual performance for astigmatic eyes. So this study clearly demonstrated that RGP-CL wear has the function to correct astigmatism and improve visual performance for astigmatic eyes.

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