

Aberration changes of the corneal anterior surface following discontinued use of rigid gas permeable contact lenses

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Abstract

• **AIM:** To record aberrations with a corneal topographic device on the anterior surface of the cornea at different time-points prior to wearing and following discontinued use of rigid gas permeable (RGP) contact lenses. The effect of wearing RGP on the anterior surface of the cornea was discussed to provide guidance for clinical refractive error correction.

• **METHODS:** The study objects were 24 eyes from 24 patients. All patients underwent identical examination procedures prior to lens use, as well as afterwards, including slit-lamp examination, non-contact tonometer measurement, computer optometry and corneal curvature measurement, subjective refraction test, and corneal topography analysis. The patients wore contact lenses everyday for 1 month and then discontinued. Corneal topographies were recorded at certain time points of 30 minutes, 1 day, 3, 7 and 14 days following use.

• **RESULTS:** Total corneal aberration at each time point following discontinued use of RGP contact lenses was less than the time point prior to use. Detailed results were as follows: root mean square (RMS) (pre)=(1.438±0.328)μm, RMS (30 minutes)=(1.076±0.355)μm, RMS (1 day)=(1.362±0.402)μm, RMS (3 days)=(1.373±0.398)μm, RMS (7 days)=(1.387±0.415)μm, and RMS (14 days)=(1.430±0.423)μm. Results showed that at 30 minutes after discontinued use of RGP contact lenses, almost all 2nd- and 3rd-order aberrations change. Quadrafoil Z10 and spherical Z12 of the 4th-order were also changed. Alterations to Z5, Z6, and Z12 at 1 day after discontinued use were significant differences compared with the time period prior to RGP use: Z5 and Z6 decreased, and Z12 increased slightly. Z5 and Z6 remained decreased at 3 days after discontinued use, but Z9 and Z10 continued to increase and Z12 returned to levels prior to RGP use. At 14 days after discontinued use, all aberrations were not

significantly different from the values prior to use.

• **CONCLUSION:** The use RGP contact lenses greatly reduced total aberration of the anterior surface of the cornea. Changes to 2nd- and 3rd-order aberrations (including Z3, Z4, Z5, Z6, Z7, and Z8) were more significant. Following discontinued use of RGP contact lenses, the majority of lower order aberrations returned to original levels in a short period of time. During this process, a transient higher order aberration appeared, but all changes disappeared within 14 days after discontinued use of RGP contact lenses.

• **KEYWORDS:** aberration; rigid gas permeable contact lens; cornea

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INTRODUCTION

The anterior surface of human cornea is not a perfect optical interface and contains many types of aberrations. The anterior and posterior surfaces of the Menicon Z[®] RGP contact lenses used in the present study were a non-spherical surface design, which resulted in near perfect optical interface. The main role of the eye in the visual process is to focus images onto the retina, and optical performance is usually related to the presence of ocular aberrations. The measurement of ocular optical aberrations has proved to be useful to understand the optical properties and image-forming capabilities of the human eye. Many eye aberrations exist, such as spherical aberration, comatic aberration (coma), and astigmatism aberration. In addition, there are many individual differences in eye wavefront aberrations [1,2]. Cornea, lens, vitreous body, and even retina could be a source of eye aberrations. Aberrations of the corneal anterior surface and intraocular aberrations overlap and interact to form a set of complex ocular optical systems. Rigid gas permeable (RGP) contact lenses are worn by a lot of ametropic patients, because of the benefits such as sharp vision, oxygen

permeability, and simple cleaning procedures. When RGP contact lenses are placed in front of the anterior surface of the cornea, the contact lens overlaps this ocular optical system. The contact lens is not a sole optical factor; it forms a tear lens at the posterior surface, because of the supporting function. This tear lens contributes to refractive error correction by compensating for slight irregularities of the corneal anterior surface. Previous studies have demonstrated that the use of RGP contact lenses can alter ocular aberrations and improve visual activity of contrast sensitivity^[3-5], and could assist in aberration control and visual activity improvement of keratoconus^[6,7]. However, long-term use of RGP lenses can result in a certain shaping effect to the corneal anterior surface, due to the high rigidity of RGP contact lenses^[8]. However, the impact of this shaping effect on corneal morphology and alteration to the corneal anterior surface following discontinued use remains poorly understood. The present study utilized a corneal topographic device to record aberrations of the corneal anterior surface at different time points prior to use and following discontinued use of RGP contact lenses. In addition, altered aberrations of the anterior surface of the cornea were analyzed. The effect of RGP contact lens use on the corneal anterior surface was discussed to provide guidance for clinical refractive error correction.

SUBJECTS AND METHODS

Subjects A total of 24 patients (10 males, 14 females) aged from 19 to 36 years (27.04 ± 4.34) participated in this study. Taking into account the relevance of two eyes, only single eye (left one) in each subject was used. The spherical equivalent refraction range was -1.00 to -6.50 (-3.57 ± 1.31) diopter sphere (DS), degrees of astigmatism were within -1.00D (-0.34 ± 0.40)DS, and the best-corrected visual activity of a single eye was not <1.0 .

The protocol adhered to the Declaration of Helsinki. Experimental purpose and possible results were provided to the patients in an oral and written form. The patients understood and gave informed consent with their signatures. The ethics committee of Shanghai Rujin Hospital approved the study.

None of the patients had previously worn RGP contact lenses. Exclusion criteria were other ocular diseases, contact lens contraindications, poor adaptation, and over-movement of contact lenses during use. The patients were assigned to two groups according to corneal aberrations prior to RGP contact lens use: 12 patients with larger aberrations were included in the large aberration group; the others were included in the small aberration group. There were 12 eyes from 12 patients in each group.

General experimental procedures All patients underwent

identical examination procedures, including slit-lamp examination (Takagi SM-70N; Nakano, Japan), non-contact tonometer measurement (Canon TX-F; Tokyo, Japan), auto-refraction and corneal curvature measurement (Nidek ARK-710A; Gamagori, Japan), subjective refraction test with a phoropter (Nidek RT-600; Gamagori, Japan), and corneal topography analysis (Allegretto Wave Topolyzer, Version 2.50; Erlangen, Germany). The corneal topography-based Sim K values, fluorophotometric assessment of tear turnover, and palpebral fissure sizes were considered for custom-tailored RGP contact lenses (Menicon Z[®]; Nagoya, Japan). The contact lens material consisted of fluoro-methacrylate and siloxanylstyrene copolymers, with a DK value of 163×10^{-11} ($\text{cm}^2/\text{second}$) ($\text{mL O}_2/\text{mL} \times \text{mmHg}$). The central thickness of the contact lens was from 0.11mm to 0.16mm depending on the degree, with a base curve radius range of 7.4-8.4mm and a diameter range of 9.0-9.6mm. The customized lens power range was -1.25D to -6.00D. The patients were asked to adapt to wearing the contact lenses according to a specific step-by-step procedure. Subsequently, the patients wore the contact lenses every day (only daytime, overnight wear was prohibited) for a month and then discontinued use. Corneal topographies were recorded at time points of 30 minutes, 1 day, 3, 7 and 14 days after discontinued use by a skilled technician and were repeated for a total of three times at each time point.

Statistical Analysis All corneal topographic data were transformed into corneal aberrations using the MATLAB ray-tracing program^[9]. The Zernike polynomials^[10], which were recommended by Optical Society of America (OSA), were used to statistically analyze 32 Zernike aberration coefficients up to the 7th order at a pupil diameter of 6mm. The analysis in this paper focused more on the first 4-order. These analyses excluded tilt and defocus aberrations. Average values from the three analyses, as well as the root mean square (RMS) values, were calculated. Study objects were assigned to two groups according to RMS values. One way ANOVA was utilized to analyze aberrations between time points following discontinued use and prior to use of RGP contact lenses in each group. Statistical software (SPSS15.0) was utilized for variance analysis between all-time points, aberration coefficients, and the groups. The P value <0.05 was considered as statistically significant.

RESULTS

Total aberration changes to the corneal anterior surface prior to use and following discontinuation of RGP contact lenses The root mean square (RMS) values of the 7 orders and 32 terms of the anterior surface cornea optical aberrations were calculated prior to use and at 30 minutes, 1

Aberration changes following discontinued use of RGP lenses¹

day, 3, 7 and 14 days after discontinued use of RGP contact lenses. Results demonstrated that the total corneal aberration at each time point within 2 weeks after discontinued use of RGP contact lenses was less than the time point prior to use. Detail values are as follows: RMS (pre)= $(1.438 \pm 0.328) \mu\text{m}$, RMS (30 minutes)= $(1.076 \pm 0.355) \mu\text{m}$, RMS (1 day)= $(1.362 \pm 0.402) \mu\text{m}$, RMS (3 days)= $(1.373 \pm 0.398) \mu\text{m}$, RMS (7 days)= $(1.387 \pm 0.415) \mu\text{m}$, and RMS (14 days)= $(1.430 \pm 0.423) \mu\text{m}$. Total RMS values at 30 minutes ($P < 0.001$) after discontinued use of RGP contact lenses were significantly different from values prior to use, but there was no significant difference ($P > 0.05$) in total RMS values between time points at 1 day, 3, 7 and 14 days after discontinued use and values prior to use. Correlation analysis between time of discontinued use and aberration values indicated significant correlation ($r = 0.963$).

In the small aberration group, results demonstrated (Figure 1) that no significant differences existed between prior to use of RGP contact lenses and discontinued use ($P > 0.1$). In the large aberration group, aberrations at 30 minutes and 1 day after discontinued use of RGP contact lenses were significantly less than prior to use ($P < 0.05$). However, there were no significant differences in aberrations between 3 days, 7 and 14 days after discontinued use of RGP contact lenses and prior to use ($P > 0.05$).

Changes to each order single aberration of the corneal anterior surface prior to RGP contact lens use and after discontinued use Because of mirror symmetry^[11,12] in aberrations from both eyes in one patient, only data from the left eyes were utilized for statistical analysis. Because the higher order ($>5^{\text{th}}$ order) aberration values were near 0 (all were $< 0.05 \mu\text{m}$) and had no clinical significance, only the 10 terms of four lower orders were used for analysis (excluding tilt aberrations). Aberration values measured at each time point following discontinued use of RGP contact lenses were compared with values prior to use.

At 30 minutes after discontinued use of RGP contact lenses, almost all 2nd- and 3rd-order aberrations were altered [including $Z_3(Z_2^{-2})$, $Z_4(Z_2^0)$, $Z_5(Z_2^2)$, $Z_6(Z_3^{-3})$, $Z_7(Z_3^{-1})$, and $Z_8(Z_3^1)$]. Quadrafoil $Z_{10}(Z_4^{-4})$ and spherical $Z_{12}(Z_4^0)$ from the 4th order were also altered. Z_8 and Z_{10} increased, while the remainder decreased. Changes in Z_5 , Z_6 , and Z_{12} at 1 day after discontinued use were significant compared to values prior to use: Z_5 and Z_6 decreased and Z_{12} increased slightly. Z_5 and Z_6 remained decreased at 3 days after discontinuation compared with values prior to use. In addition, $Z_9(Z_3^3)$ and Z_{10} increased, and Z_{12} returned to levels prior to use. At 7 days after discontinuation, only Z_9 was altered, while the remainder returned to original levels. At 14 days after

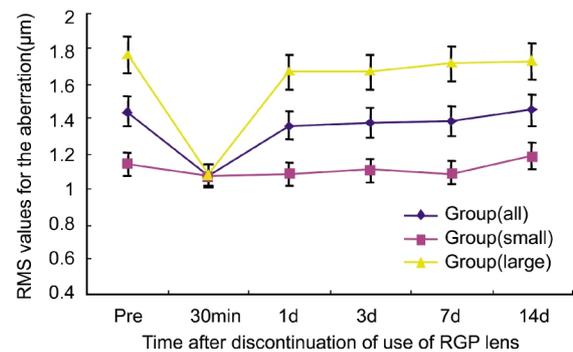


Figure 1 Aberration changes of the anterior surface of the cornea after stopping wearing rigid gas permeable contact lens.

discontinuation, all aberrations demonstrated no significant difference to original values prior to use.

DISCUSSION

Because the contact material was rigid, long-term use is bound to affect the anterior surface shape of the cornea. Results from the present study also supported this theory.

Changes in total RMS values of the corneal anterior surface prior to use and followed discontinued use of RGP contact lenses The average total RMS values of the corneal anterior surface at each time point after discontinued use were less than prior to use. This change was most significant at 30 minutes after discontinuation. With increasing time, the changes gradually decreased.

Previous studies^[3,4,8] have demonstrated that the effect of the eye aberrations due to RGP contact lens using is related to the original aberrations. If the original aberration is large, decreased aberration following RGP contact lens use will be significant. If, however, original aberration is small, the reduced aberration following RGP contact lens use will not be significant, and aberration could even increase. These results indicated that interaction of RGP contact lenses and corneal anterior surface was related to original corneal morphology. In the present study, the patients were assigned to two groups according to original aberrations: large and small aberrations. Results from the large aberration group demonstrated that altered aberrations to the corneal anterior surface were visible at 30 minutes and 1 day after discontinued use of RGP contact lenses. However, in the small aberration group, the RMS values were not altered at all, even at 30 minutes after discontinued use. These results confirmed that RGP contact lenses altered the anterior surface of the cornea in accordance with the posterior surface shape of RGP contact lenses.

Alterations to single order aberration values of the corneal anterior surface prior to and after discontinued use of RGP contact lenses Zernike polynomials advocated by Thibos^[13] were defined with polar coordinates (ρ , θ) and different directions would be displayed in different polarity.

Therefore, to avoid errors resulting from sign differences (positive and negative), only data from the left eyes were used for the single-term aberration study.

Statistical analyses of data at 30 minutes after discontinued use and prior to use of RGP contact lenses demonstrated altered aberrations in 4 lower orders of all 10 terms, except Z9 and Z11. The average values revealed decreased Z3, Z4, Z5, and Z12, as well as increased Z8 and Z10. However, Z6 and Z7 signals changed from positive values prior to RGP use to negative values after RGP use. Aberration values of Z4, Z5, Z8, and Z12 were larger (Figure 2), and the alterations contributed to the total RMS values. For these four terms, only Z8 increased and the remainder decreased. Therefore, the total RMS value at 30 minutes after discontinued use was decreased. The causes for these changes were analyzed. Theoretically, in 2nd-order aberrations, altered astigmatism should be related to the shaping effect of the posterior surface of the contact lens. However, the effect of decreased spherical defocus related to the direct plashing effect of the RGP contact lenses, as well as the shaping function of RGP compared with Ortho K contact lenses require further studies. In addition, decreased spherical aberration should be related to the non-spherical design of the posterior surface of the RGP contact lens. Previous studies^[14, 15] have demonstrated that spherical aberration should be correctable in higher order aberrations, because spherical aberration is not similar to odd-number order aberrations, such as coma. Spherical aberration is axial symmetric and is not affected by the rotation of contact lenses. Some results^[16] have shown that off-centered and moving RGP contact lenses can produce coma. Therefore, changes in Z7 and Z8 following discontinued RGP contact lens use should be related to the shaping effect of visual axis deviation as a result of this contact lens characteristic.

At 1 day after discontinued RGP contact lens use, Z3, Z4, Z7, Z8, and Z10 values returned to original levels, Z5 and Z6 maintained the changing trend, and Z12 exhibited abnormal reversing and slightly increased. At 3 days after discontinued use, Z12 values returned to original levels, and Z9 and Z10 increased. At 7 days after discontinued use, only Z9 changed slightly, while the remained displayed no significant difference compared with values prior to use. At 14 days after discontinued use, all values returned to original levels. According to these changes, the results suggested that use of RGP contact lenses temporarily altered all corneal aberrations. Z3, Z4, Z7 and Z8 values return to original levels at 1 day, Z12 at 3 days, and Z5, Z6 at 7 days after discontinued use. In addition, within 7 days after discontinued use, higher order aberrations disappeared and reappeared, or

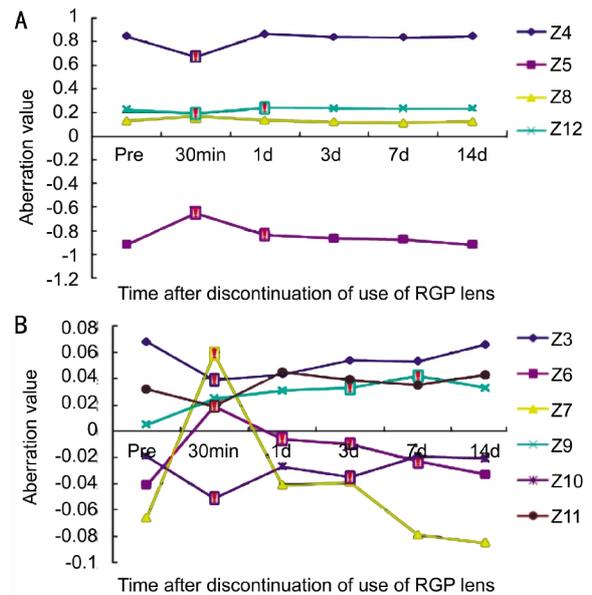


Figure 2 Single aberration changes after stopping wearing rigid gas permeable contact lens A: Z4, Z5, Z8 and Z12; B: Z3, Z6, Z7, Z9, Z10 and Z11. Red "!" represents a significant change.

would appear gradually after discontinued use, or resulted in a reciprocal change. A previous study^[17] demonstrated that the shaping effect of RGP contact lenses was primarily related to lower order aberrations, but resulted in irregular effects to higher order aberrations, which was consistent with results from the present study. It was presumed that selectivity and uncertainty of this shaping effect correlated with optical precision of the posterior surface of RGP contact lenses, as well as with movement of contact lenses, tears lens, contact lens deformation, *etc.*

In conclusion, the use of RGP contact lenses greatly reduced total aberration of the corneal anterior surface. This change was most significant at 30 minutes after discontinued use, gradually decreased with time, and returned to original levels after 1 day of discontinued use. Changes in 2nd- and 3rd-order aberrations (including Z3, Z4, Z5, Z6, Z7, and Z8) were most significant, and the use of RGP contact lenses exhibited a large corrective effect on spherical aberration (Z12). Following discontinued use of RGP contact lenses, Z3, Z4, Z7, and Z8 values returned to original levels within 1 day and Z12 returned to normal values after 3 days. The present study demonstrated that after discontinued use, lower order aberrations returned to original levels within a short amount of time. During this process, a transient higher order aberration appeared, but all changes disappeared within 14 days after discontinued use of RGP contact lenses.

There are many unknown mechanism of these changes, looking forward to the further research on the change of corneal epithelium after wearing, posterior corneal surface changes *etc.*

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