• Clinical Research •

Effects of rigid gas permeable contact lens on morphological parameters and vision-related quality of life in keratoconus patients

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Received: 2022-02-01 Accepted: 2022-09-05

Abstract

● **AIM:** To evaluate the effect of rigid gas permeable contact lens (RGP-CL) on corneal morphological parameters and vision-related quality of life in keratoconus (KC) patients.

● **METHODS:** Totally 57 eyes of 30 KC patients who were followed-up for more than two years, including 17 RGP wearers (32 eyes) and 13 non-wearers (25 eyes) were retrospectively analyzed. Initial medical history and corneal topography were collected at baseline. Corneal topography, corneal aberration, optical coherence tomography, and vision-related quality of life questionnaires were performed at the last follow-up.

● **RESULTS:** According to corneal topography, increase of the flattest keratometric values was higher in RGP wearers than in non-wearers (P=0.038). The morphological parameters, including symmetry index of front corneal curvature (P=0.004) and Baiocchi-Calossi-Versaci index front (P=0.047), were lower in RGP wearers than in non-wearers. Vertical coma was smaller in RGP wearers than non-wearers in 3.0, 5.0, 6.0, and 7.0 mm pupil diameters, respectively (P<0.05). The environmental triggering domain of ocular surface disease index was worse in RGP wearers as compared to non-wearers (P=0.003). At the last follow-up, there were no significant differences in constituent ratios of KC progression, corneal thickness topography, epithelial thickness topography, morphological parameters of corneal topography, and other questionnaire scores between the two groups (all P>0.05).

● **CONCLUSION:** Long-term use of RGP does not worsen KC but may cause corneal epithelial remodeling to increase symmetry of corneal anterior surface, reduce corneal vertical coma and improve visual quality. However, RGP wearing causes a slight decrease in vision-related quality of life. The occurrence of ocular surface symptoms is mainly associated with environmental triggering factors.

● **KEYWORDS:** keratoconus; rigid gas permeable contact lens; morphological parameters; corneal aberration; vision-related quality of life

DOI:10.18240/ijo.2022.11.07

Citation: Xu Y, Wang Y, Zhang XF. Evaluation of rigid gas permeable contact lens on morphological parameters and vision-related quality of life in keratoconus patients. *Int J Ophthalmol* 2022;15(11):1772-1781

INTRODUCTION

Keratoconus (KC) is a progressive, bilateral and asymmetrical corneal ectasia that may lead to severe visual impairment due to the irregular astigmatism caused by corneal thinning[1-2]. It not only causes myopia and irregular astigmatism but also leads to thinning, steep and even scarring of the central and mid-peripheral cornea, resulting in severe vision loss[3]. It is typically diagnosed during peak education, income-earning and child-rearing years, and has a major impact on vision-related quality of life[4].

The safety and efficacy of corneal cross-linking for controlling KC progression has been recently confirmed[5-8]. In mild cases of KC, spectacles or soft contact lenses can be used to help correct myopia and astigmatism[9]. For moderate and advanced cases, the rigid gas permeable contact lens (RGP-CL) can be used to improve the visual quality of patients by creating a thin lacrimal lens that neutralizes most of the corneal astigmatic error and may decrease higher-order aberrations[10]. There is no definitive treatment for KC patients. Currently, RGP-CL remains the most common conservative treatment and is still necessary for improving vision quality in KC patients[11].

RGP-CL is considered to provide good vision, control KC progression, and delay the need for surgeries. Ultraviolet light exposure was suggested to be a risk factor for KC on account of oxidative stress of corneal epithelial cells and ultraviolet-induced oxidative toxicity of endothelial cells. RGP-CL

may reduce the absorption of ultraviolet light but no direct research pointed this[12]. Wearing RGP-CL had no effect on KC progression based on corneal topographic evaluation over 5y[13]. Short-term wearing of RGP-CL was reported to change the vertical coma $\left(Z_3^{-1}\right)$ of KC[14]. The effect of wearing RGP-CL on corneal epithelium and vision-related quality of life in long-term follow-up of KC patients has not been comprehensively assessed. Our study analyzed KC patients who were followed-up for more than two years including 25 male and 5 female patients. It also comparatively analyzed corneal epithelial thickness and corneal aberrations in KC patients wearing RGP-CL and spectacles. Meanwhile, some questionnaires were administered to evaluate the long-term efficacy and safety of wearing RGP-CL for KC.

SUBJECTS AND METHODS

Ethical Approval The study protocols were approved by the Ethics Committee of the Dushu Lake Hospital Affiliated to Soochow University and adhered to the tenets of the Declaration of Helsinki. All the participants were informed that they would participate in the study. All data would be de-identified and only reported in the aggregate. All participants acknowledged an informed consent statement in order to participate in the study.

Subjects and Clinical Examinations We retrospectively enrolled and analyzed the patients with clinically diagnosed KC who were followed-up for more than two years in the Ophthalmology Department. All participants were of Han ethnicity and no RGP wearing history before the beginning of the follow-up period. The choice of wearing RGP-CL or spectacles was solely made by the KC patients themselves. We collected the data from a series of comprehensive examinations performed for all the KC patients before enrollment into the study and at the last follow-up, including initial medical history, corneal topography, corrected visual acuity at diagnosis, and anterior segment photography, corneal topography, corneal aberration, corneal optical coherence tomography (OCT), corrected visual acuity and vision-related quality of life questionnaires at the last follow-up. For the RGP-CL wearers, all the assessments were performed at least one hour after the lenses were removed. Patients with the following conditions were not eligible for enrollment: 1) history of ocular surgeries, 2) other ocular diseases except KC and refractive error, such as glaucoma, cataract, strabismus, amblyopia and retinal diseases, 3) KC secondary to corneal refractive surgery, 4) severe irregular corneal anterior surface, which could not be effectively examined by corneal topographer when diagnosed, 5) pregnant, lactating patients or patients taking medicine like oral contraceptives.

Diagnostic Criteria of Keratoconus Diagnostic criteria of KC[15]: having typical KC topographic features and at least one of the following signs under the slit lamp microscopy examination of the cornea: thinning of the corneal stroma, tapered forward bulging, Vogt's striae, Fleischer ring or corneal scarring typical of KC.

In this study, patients with one of the following conditions were considered as progressing KC eyes: 1) increase in average keratometry values greater than 0.5 D, 2) the best corrected visual acuity decreased by more than one line, 3) transformation of corneal topographic type into irregular type, 4) new corneal scars, 5) corneal edema caused by rupture of Descemet's membrane.

Rigid Gas Permeable Contact Lens Fitting The RGP-CLs used by the KC patients were derived from a fluorosilicone acrylate material with the Rose K (Boston XO, Freshkon, Shanghai, China), and these patients did not have any history of using different contact lenses. The diameters of their RGP-CLs ranged from 9.2 to 9.6 mm. The RGP-CL fitting was accomplished by the same experienced expert. The fitting was based on the "three-point-touch" method (Figure 1). The lenses with the corresponding base curve and diameter according to the corneal topographical parameters were selected for trial wear. After about 30min of adaptation, the lens fit was evaluated by fluorescein staining and dynamic observation under cobalt blue light of the slit lamp microscope. After appropriate fitting, the final RGP-CL prescription parameters were determined by optometry with RGP-CL wearing. All the RGP wearers in this study fit well during the follow-up period. The patients were required to wear the RGP-CL for 6-8h a day. The follow-up was conducted every 1-3mo. During the follow-up, the fit of RGP-CL, the status of cornea and conjunctiva, and whether the lens was scratched or damaged were observed for advising the patients to continue wearing, stop wearing or replace the lens. No patients in this study stopped wearing RGP during the follow-up period. The lenses were changed every 1.5-2y, and the prescription parameters were adjusted according to the corneal morphology and diopter.

Corneal Topography The corneal topographer used was TMS-4 (Tomy, Japan). All the examinations were performed by the same technician. Three successful measurements were performed, and the subjects were asked to blink after each measurement. The best quality images were chosen (each axial deviation of *X*, *Y*, *Z* was less than 0.3 mm). The steepest keratometric values (Ks), the flattest keratometric values (Kf), the average keratometric values (AveK), corneal astigmatism (Cyl), corneal surface regularity index (SRI), and corneal surface asymmetry index (SAI) were recorded and analyzed both at the initial diagnosis and the last follow-up.

Corneal Pachymetry and Epithelial Thickness Maps A Fourier domain OCT system RTVue-100 (Optovuelnc, Fremont, CA, USA) was used to acquire corneal pachymetry

and epithelial thickness distribution. The examinations were performed by the same technician in a semi-dark environment. No drugs affecting tear dynamics were used in the two hours before the examination. The system operates at an 830-nm wavelength and has a scanning speed of 26 000 axial scans per second[16]. In this study, the cornea was scanned with the "Pachymetrywide" mode to obtain corneal thickness and corneal epithelial thickness (units in micrometers) in a circular area with a center of the pupil center and a diameter of 9.0 mm. The distribution of thickness was represented by a topographic map. The corneal thickness and corneal epithelial thickness were evaluated in 25 areas in the following four regions (Figure 2): 1) one central zone within 0 to 2.0 mm diameter (C), 2) eight paracentral zones from 2.0 to 5.0 mm diameter (S1, ST1, T1, IT1, I1, IN1, N1, SN1), 3) eight mid-peripheral zones from 5.0 to 7.0 mm diameter (S2, ST2, T2, IT2, I2, IN2, N2, SN2), 4) eight peripheral zones from 7.0 to 9.0 mm diameter (S3, ST3, T3, IT3, I3, IN3, N3, SN3). The average corneal thickness and corneal epithelial thickness of each zone were obtained for each eye.

Corneal Morphological Parameters and Aberrations The Sirius Corneal Topographer (CSOInc, Italy) was used to examine the corneal aberration in a semi-dark environment. The same device with the same operator was used to obtain three scans for each eye, and the best scan was selected. Cut-off for image acquisition quality was set as Scheimpflug images coverage ≥90%, centration ≥90% and keratoscopy coverage ≥80%. The morphological parameters of KC were detected and analyzed by Sirius corneal topographer, including Baiocchi-Calossi-Versaci index (BCV), symmetry index of front corneal curvature (SIf), keratoconus vertex front (KVf), Baiocchi-Calossi-Versaci index front (BCVf), symmetry index of back corneal curvature (SIb), keratoconus vertex back (KVb), Baiocchi-Calossi-Versaci index back (BCVb), corneal thickness at the apex (CTA), anterior chamber depth (ACD), corneal volume (CV), corneal asphericity of anterior surface in 6 mm (Q1), corneal asphericity of posterior surface in 6 mm (Q2), corneal asphericity of anterior surface in 8 mm (Q3), corneal asphericity of posterior surface in 8 mm (Q4), the thinnest thickness of the cornea (Thk), and the diagnostic classification of patients (Class) analyzed by Sirius.

The corneal astigmatism, total higher-order aberrations (HOA) and spherical aberration $\left(Z_4^0\right)$ for 6.0 mm pupil diameters were recorded in absolute values. The horizontal coma $\left(Z_3^1\right)$, Z_3^{-1}, vertical trefoil $\left(Z_3^{-3}\right)$, and oblique trefoil $\left(Z_3^3\right)$, for 3.0, 5.0, 6.0 and 7.0 mm pupil diameters, respectively, were recorded in positive or negative values rather than absolute.

National Eye Institute-Vision Function Questionnaire 25 At the last follow-up, the patient's visual quality was assessed using the Chinese version of National Eye Institute-Vision Function Questionnaire 25 (NEI-VFQ-25). Before filling out the questionnaire, the same doctor explained the purpose and significance of the questionnaire to all patients and obtained their consent. The questionnaire consisted of 25 questions in 12 domains, including general health, general vision, ocular pain, near vision, distance vision, vision-specific social function, vision-specific mental health, vision-specific role difficulties, vision-specific dependency, driving, color vision and peripheral vision. Each option was scored according to the score requirements for statistical analysis.

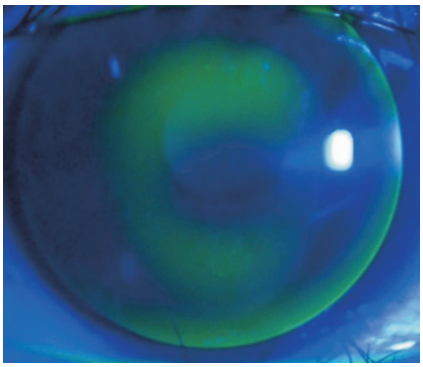

Figure 1 Rigid gas permeable contact lens ideal fit in the eye with keratoconus Rigid gas permeable contact lens ideal fit according to "three-point-touch" method with an apparent subtle darkening of the fluorescein profile over the corneal apex.

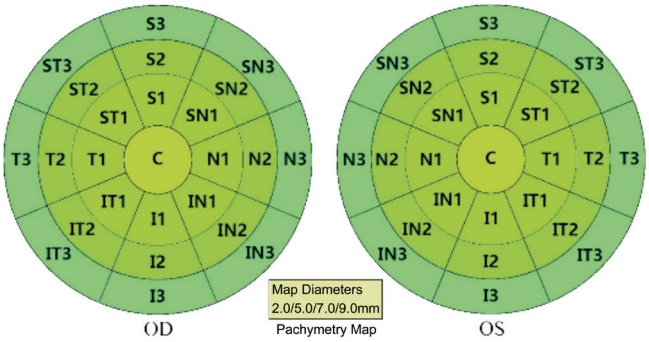

Figure 2 Twenty-five zones of corneal thickness or epithelial thickness in both eyes.

Ocular Surface Disease Index At the last follow-up, the Ocular Surface Disease Index (OSDI) was used to assess the patient's ocular symptoms. Before filling out the questionnaire, the same doctor explained the purpose and significance of the questionnaire to all patients and obtained their consent. The questionnaire consisted of 12 questions in three domains, assessing ocular symptoms, visual function-related, and environmental triggering factors. All the time, most of the time, half of the time, some of the time and none of the time were scored 100, 75, 50, 25 and 0 points, respectively. The total score of OSDI within 0-20, 21-45 and 46-100 was divided into mild, moderate, and severe symptoms, respectively.

Statistical Analysis Data were analyzed by statistical package SPSS version 17.0 (version 17.0, Chicago, Illinois, USA). Normality of data measured by corneal topographer, Fourier domain OCT and Sirius corneal topographer were analyzed using the Shapiro-Wilk test, and expressed as mean±standard deviation (SD). The comparison of the constituent ratio of the corneal topographic patterns between RGP-CL wearers and non-wearers was performed by Chi-square test of the R×C table. The normality test (single-sample Kolmogorov-Smirnov test) was performed on the score of each item of NEI-VFQ-25 and OSDI questionnaires. The data with normal distribution and homogeneity of the variance in RGP-CL wearers and non-wearers were compared with two independent samples *t*-test. The data that did not conform to the normal distribution were compared with Mann-Whitney *U* test. $P<0.05$ was considered statistically significant.

RESULTS

This study included three stages. In the first stage, we evaluated morphological parameters of KC based on corneal topography and OCT. In the second stage, corneal aberrations based on Sirius corneal topography were analyzed. In the third stage, the vision-related quality of life questionnaires, including NEI-VFQ-25 and OSDI, were recruited and elaborated.

Basic Information A total of 30 KC patients (57 eyes) were followed-up for more than two years, and divided into two groups, including 17 RGP-CL wearers (32 eyes) and 13 non-wearers (25 eyes). Demographic characteristics of these participants are listed in Table 1. The stage of KC was graded as mild, moderate, and severe according to Ks. Baseline data were balanced across the distribution of stages ($\chi^2=1.674$, $P=0.433$), age of diagnosis, gender, and duration of follow-up ($P>0.05$).

In addition, medical histories of the subjects were collected. Of the 17 RGP-CL wearers, one had a history of smoking, one had asthma, four had allergic rhinitis, one had eczema and one had acne. Meanwhile, of the 13 non-wearers, four had a history of smoking, five had allergic rhinitis, four had eczema and one had psoriasis. None of the subjects had a history of systemic diseases such as rheumatoid arthritis, systemic lupus erythematosus, Sjögren's syndrome, ankylosing spondylitis or diabetes.

Corneal Topographic Parameters Analysis The corneal topographic parameters (Ks, Kf, AveK, Cyl, SRI, and SAI) were compared between RGP-CL wearers and non-wearers at the baseline (Figure 3A-3F), as well as the last follow-up (Figure 3G-3L). In addition, the differences (ΔKs, ΔKf, ΔAveK, ΔCyl, ΔSRI, and ΔSAI) between the baseline and the last follow-up were also compared (Figure 3M-3R). As illustrated in Figure 3, significant difference was observed in the increase of DKf, which was higher in RGP-CL wearers than non-wearers ($P=0.038$). No significant difference was found in other corneal topographic parameters between the two groups.

Analysis of Keratoconus Progression A total of 19 eyes developed progressive ectasia and 13 eyes not until the last follow-up as compared to the baseline in RGP-CL wearers. Similarly, nine eyes developed progressive ectasia, while 16 eyes did not among the non-wearers. According to the Chi-square test, the constituent ratio of KC progression was balanced between the two groups ($\chi^2=3.068$, $P=0.080$).

Corneal Thickness and Corneal Epithelial Thickness Analyzed by OCT At the last follow-up, the difference of corneal and epithelial thicknesses was set up visually by OCT. The mean thinnest corneal thickness was 448.31±50.32 μm in RGP-CL wearers and 463.28±55.17 μm in non-wearers ($P=0.290$). The mean thinnest corneal epithelial thickness was 41.47±6.09 μm in RGP-CL wearers and 43.00±5.35 μm in non-wearers ($P=0.325$). In addition, no statistically significant differences were found in the average thicknesses of cornea or corneal epithelium in the 25 zones between RGP-CL wearers and non-wearers ($P>0.05$; Figure 4). Hence, the corneal and epithelial thicknesses were comparable between the two groups.

Morphological Parameters Analyzed by Sirius Corneal Topography Table 2 illustrates the corneal morphological characteristics in both anterior and posterior surfaces. The patients wearing RGP-CL were significantly associated with lower SIf ($P=0.004$) and BCVf ($P=0.047$). In addition, according to the Chi-square test, the diagnostic classification of patients analyzed by Sirius did not show statistically significant difference in the two groups ($\chi^2=1.265$, $P=0.867$).

Corneal Aberrations Analyzed by Sirius Corneal Topography Corneal aberrations between RGP-CL wearers and non-wearers were also compared (Table 3). As a result, the vertical coma $\left(Z_3^{-1}\right)$ was smaller in the RGP-CL wearers as compared to non-wearers in 3.0, 5.0, 6.0, and 7.0 mm pupil diameters, respectively, while there were no significant differences between the two groups in $\left(Z_3^{1}\right)$, $\left(Z_3^{-3}\right)$, and $\left(Z_3^{3}\right)$. Corneal astigmatism ($P=0.714$), total HOAs ($P=0.079$) and $\left(Z_4^{0}\right)$ ($P=0.827$) didn't show significant differences between RGP-CL wearers and non-wearers.

Analysis of NEI-VFQ-25 and OSDI A total of 29 out of the 30 patients in this study completed the NEI-VFQ-25 and the OSDI questionnaires. Baseline data were comparable across the age of diagnosis ($P=0.100$), gender ($P=0.945$) or follow-up period ($P=0.789$) between the RGP-CL wearers and non-wearers. Consequently, there were no significant differences in the total score of NEI-VFQ-25 ($P=0.291$) and the scores of 12 domains between the RGP-CL wearers and non-wearers ($P>0.05$; Table 4). According to OSDI, the score

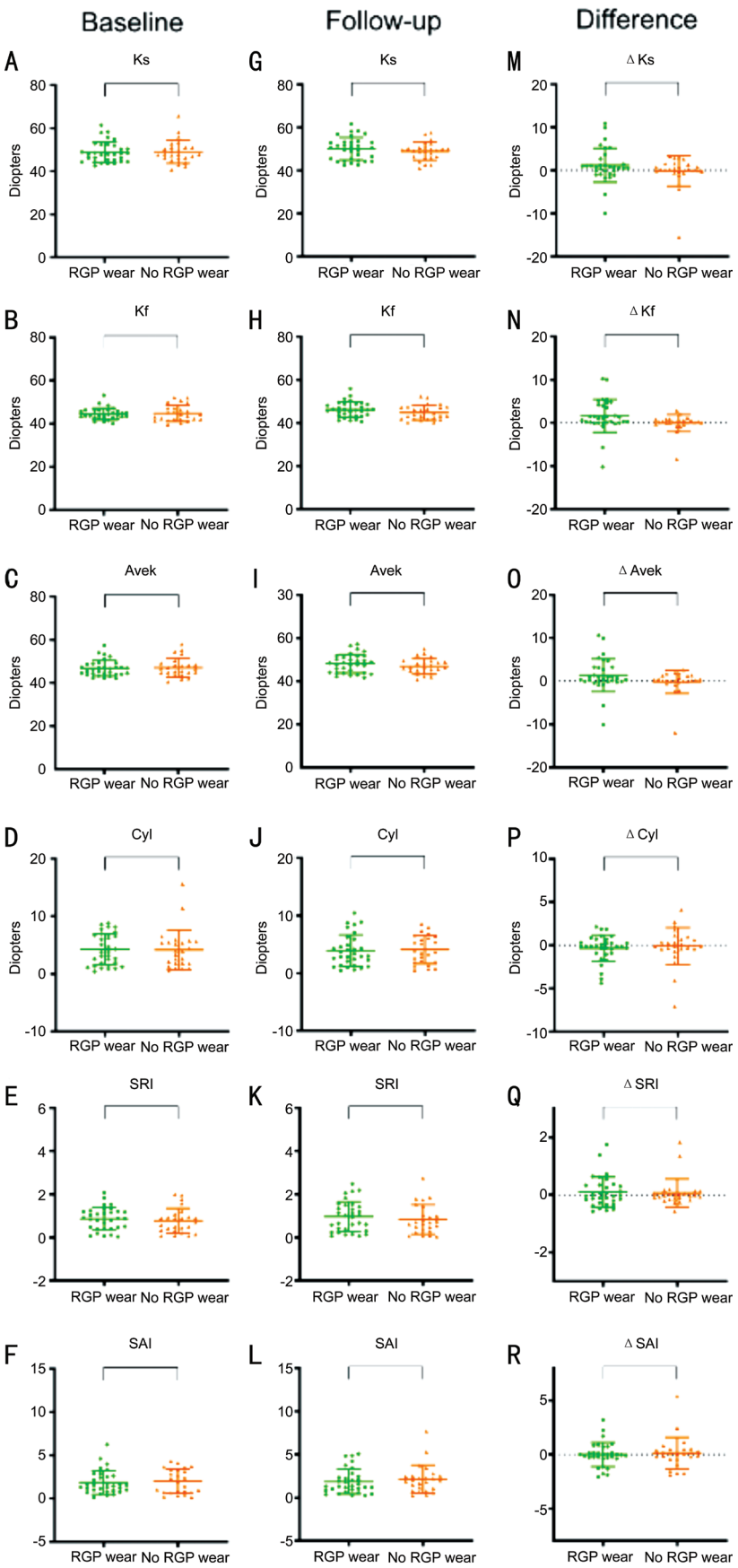

Figure 3 Corneal topographic parameters between RGP-CL wearers and non-wearers A-F: The corneal topographic parameters (Ks, Kf, AveK, Cyl, SRI and SAI) were compared between RGP-CL wearers and non-wearers at baseline; G-L: The corneal topographic parameters (Ks, Kf, AveK, Cyl, SRI, and SAI) were compared between RGP-CL wearers and non-wearers at the last follow-up; M-R: The differences (ΔKs, ΔKf, ΔAveK, ΔCyl, ΔSRI, and ΔSAI) between the baseline and the last follow-up were also compared. Significant difference was found in the increase of ΔKf, which was higher in RGP-CL wearers than non-wearers (P=0.038). RGP-CL: Rigid gas permeable contact lens.

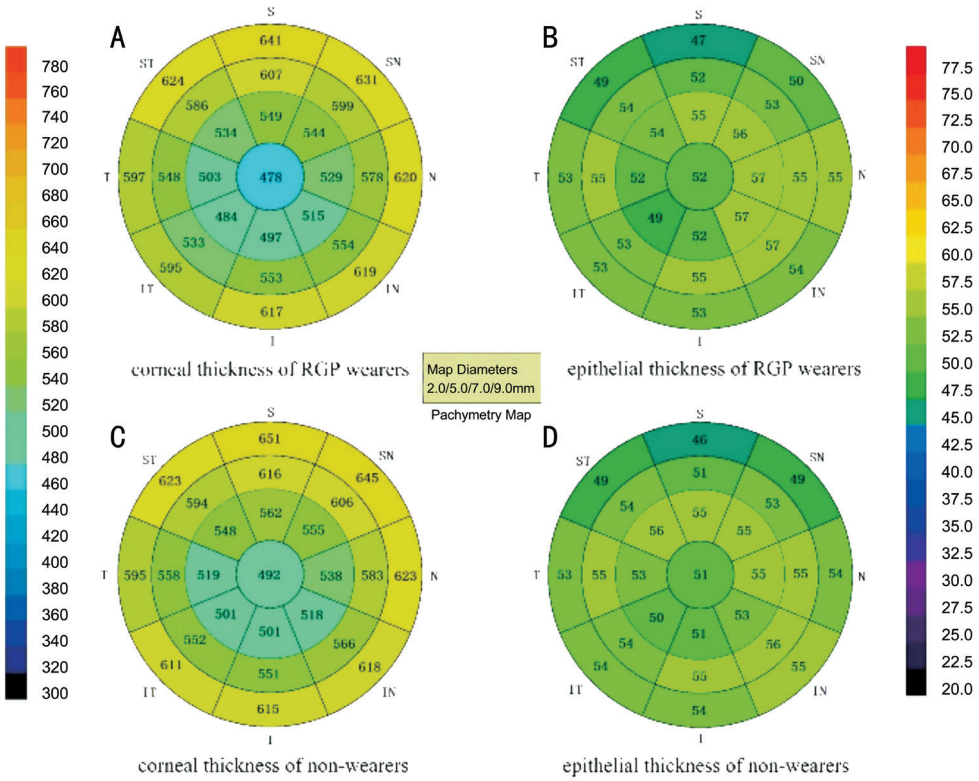

Figure 4 Comparison of OCT parameters between RGP-CL wearers and non-wearers A: Average corneal thicknesses of 25 zones in RGP-CL wearers; B: Average epithelial thicknesses of 25 zones in RGP-CL wearers; C: Average corneal thicknesses of 25 zones in non-wearers; D: Average epithelial thicknesses of 25 zones in non-wearers. RGP-CL: Rigid gas permeable contact lens.

Table 1 Demographic characteristics of subjects in the study

Parameters	Total	RGP-CL wear	No RGP wear	*P*
Subjects (eyes)	57	32	25	
Mild (Ks<45 D)	12	8	4	
Moderate (45≤Ks≤52 D)	31	15	16	
Severe (Ks>52 D)	14	9	5	
Age of diagnosis (y)	22.77±9.60	20.44±5.77	25.76±12.46	0.057
Age range (y)	9-62	9-32	12-62	
Gender (male/female)	47/10	26/6	21/4	0.786
Duration of follow-up (mo)	77.61±27.12	79.06±27.68	75.76±26.83	0.652
Duration of follow-up range (mo)	25-133	25-126	41-133	
Education level above high school (cases)	30	17	13	
Social medical insurance (with/without)	28/2	16/1	12/1	
Smoking history	5	1	4	
Asthma	1	1	0	
Allergic rhinitis	9	4	5	
Systemic disease				
Eczema	5	1	4	
Psoriasis	1	0	1	
Acne	1	1	0	

RGP-CL: Rigid gas permeable contact lens.

of environmental triggering domain was significantly higher in RGP-CL wearers as compared to non-wearers (*P*=0.003). In addition, five patients (29.41%) were in the mild symptom group, nine patients (52.94%) were in the moderate symptom group and three patients (17.65%) were in the severe symptom group, respectively, among the RGP-CL wearers. Five patients (41.67%) were in the mild symptom group, six patients (50.00%) were in the moderate symptom group and one patient (8.33%) was in the severe symptom group, respectively, among the non-wearers. There was no significant difference between

Table 2 Morphological parameters analyzed by Sirius corneal topography mean±SD

Parameters	RGP-CL wear	No RGP wear	*P*
BCV (μm)	2.52±1.73	3.33±2.31	0.133
SIf (D)	3.37±3.10	6.19±4.09	0.004
KVf (μm)	24.66±14.24	31.32±23.41	0.190
BCVf (D)	2.34±1.65	3.44±2.45	0.047
SIb (D)	1.37±0.96	1.56±0.93	0.463
KVb (μm)	68.72±41.93	72.72±55.94	0.759
BCVb (D)	2.85±1.95	3.33±2.27	0.398
CTA (μm)	475.91±61.11	488.00±46.16	0.414
ACD (μm)	3.40±0.45	3.22±0.37	0.096
CV (mm^3)	55.91±2.87	55.90±2.57	0.998
Q1	-1.12±0.63	-1.24±0.97	0.581
Q2	-1.56±0.96	-1.66±1.18	0.718
Q3	-1.01±0.50	-1.11±0.71	0.551
Q4	-1.26±0.75	-1.29±0.80	0.889
Thk (μm)	451.84±54.43	471.24±59.04	0.204
Class			
Abnormal or treated	3	1	
Keratoconus compatible	20	18	
Normal	2	2	
Not enough data to classify	1	1	
Suspect keratoconus	6	3	

BCV: Baiocchi Calossi Versaci index; SIf: Symmetry index front; KVf: Keratoconus vertex front; BCVf: Baiocchi Versaci front index; SIb: Symmetry index back; KVb: Keratoconus vertex back; BCVb: Baiocchi Versaci back index; CTA: Corneal thickness at the apex; ACD: Anterior chamber depth; CV: Corneal volume; Q1: Corneal asphericity of anterior surface in 6 mm; Q2: Corneal asphericity of posterior surface in 6 mm; Q3: Corneal asphericity of anterior surface in 8 mm; Q4: Corneal asphericity of posterior surface in 8 mm; Thk: The thinnest thickness of the cornea; Class: The diagnostic classification of patients analyzed by Sirius. RGP-CL: Rigid gas permeable contact lens.

the RGP-CL wearers and non-wearers in the classification of symptom groups (χ^2=0.761, *P*=0.684; Table 5).

DISCUSSION

Currently, RGP-CL is the most widely used conservative management for KC patients to improve visual acuity[17], but whether RGP-CL is beneficial to control the progression of KC remains controversial. Proper wearing of RGP-CL was unlikely to impact the progression of KC based on tomographic evaluation over 5-6y[13]. Many studies have suggested that RGP-CL can significantly reduce total HOA, improve vision and visual quality in KC patients[18-19]. In contrast, KC patients younger than 20 years old have poor corneal toughness and RGP-CL wearing is a risk factor for corneal irregularities, corneal abrasion, and even require corneal transplantation[20]. Bitirgen *et al*[21] studied the corneal microstructure of KC after

Table 3 Ocular HOAs between RGP-CL wearers and non-wearers mean±SD

Diameter	Zernike terms (μm)	RGP-CL wear	No RGP wear	*P*
6 mm	Astigmatism	2.31±1.48	2.46 ±1.45	0.714
6 mm	Total HOA	1.75±1.14	2.51±1.84	0.079
3 mm	Z_3^{-3}	0.00±0.26	0.13±0.27	0.069
	Z_3^{-1}	-0.07±0.50	-0.34±0.30	0.023
	Z_3^{1}	-0.01±0.21	0.03±0.12	0.431
	Z_3^{3}	0.04±0.39	-0.01±0.15	0.536
5 mm	Z_3^{-3}	0.25±0.51	0.42±0.53	0.221
	Z_3^{-1}	-0.57±0.72	-1.31±1.06	0.003
	Z_3^{1}	0.10±0.58	0.01±0.26	0.462
	Z_3^{3}	0.05±0.37	-0.03±0.30	0.349
6 mm	Z_3^{-3}	0.33±0.61	0.55±0.70	0.203
	Z_3^{-1}	-0.85±0.99	-1.92±1.73	0.009
	Z_3^{1}	0.10±0.88	0.02±0.35	0.642
	Z_3^{3}	0.05±0.40	-0.04±0.40	0.398
7 mm	Z_3^{-3}	0.25±0.79	0.61±0.93	0.122
	Z_3^{-1}	-1.13±1.25	-2.45±2.39	0.017
	Z_3^{1}	0.09±1.26	0.01±0.47	0.740
	Z_3^{3}	0.03±0.57	-0.08±0.57	0.464
6 mm	Spherical aberration $\left(Z_0^4\right)$	0.32±0.30	0.35±0.51	0.827

HOA: Higher-order aberration; RGP-CL: Rigid gas permeable contact lens.

Table 4 NEI-VFQ-25 total and subscale scores of RGP-CL wearers and non-wearers

Parameters	RGP-CL wear (*n*=17)		No RGP wear (*n*=12)		*P*
	Mean±SD	Min-max	Mean±SD	Min-max	
General health	57.35±24.63	0-75	47.92±22.51	25-75	0.232
General vision	63.53±16.18	40-80	51.67±13.37	20-60	0.056
Ocular pain	77.21±17.80	25-100	85.42±16.35	50-100	0.074
Near activities	79.59±25.35	0-100	86.11±20.22	25-100	0.230
Distance activities	77.94±24.31	25-100	81.94±23.61	0-100	0.416
Social functioning	87.50±21.54	25-100	88.54±16.45	50-100	0.821
Mental health	76.10±32.45	0-100	72.92±27.69	0-100	0.193
Role difficulties	80.15±20.21	50-100	76.04±23.86	25-100	0.567
Dependency	75.00±35.36	0-100	79.17±25.00	0-100	0.851
Driving	76.63±28.58	0-100	84.72±21.78	25-100	0.203
Color vision	89.71±21.76	25-100	93.75±11.31	75-100	0.929
Peripheral vision	79.41±25.36	25-100	85.42±12.87	75-100	0.807
Total score	75.99±28.00	0-100	79.47±23.83	0-100	0.291

RGP-CL: Rigid gas permeable contact lens.

Table 5 OSDI total and subscale scores between RGP-CL wearers and non-wearers

Parameters	RGP-CL wear (*n*=17)		No RGP wear (*n*=12)		*P*
	Mean±SD	Min-max	Mean±SD	Min-max	
Symptom	23.53±19.82	0-75	14.58±9.48	0-33.33	0.160
Visual function	28.68±20.67	0-79.17	32.29±26.30	0-91.67	0.682
Environment trigger	40.20±24.69	8.33-83.33	16.67±14.21	0-41.67	0.003
Total score	30.27±19.28	2.08-79.17	23.96±15.22	0-52.08	0.354

RGP-CL: Rigid gas permeable contact lens.

RGP-CL wearing, and found that wearing RGP-CL promoted further reduction of corneal epithelial basal cells and superficial corneal stromal cells in KC patients. Moreover, wearing RGP-CL can induce the overexpression of inflammation markers such as IL-6, IL-8/CXCL8, MMP-9, and MMP-13 in tears of KC patients[22].

In this study, KC patients with more than two-year followed-up were observed. There were no significant differences in the corneal topographic parameters (Ks, Kf, AveK, Cyl, SRI, and SAI) and corneal topography patterns between RGP-CL wearers and non-wearers at baseline or at the last follow-up. The increase of the flattest keratometric values was significantly higher among the RGP-CL wearers than the non-wearers. No significant differences were found in the constituent ratio of progressive KC and the changes of the other corneal topographic parameters (ΔKs, ΔAveK, ΔCyl, ΔSRI, and ΔSAI) between the baseline and the last follow-up in RGP-CL wearers and non-wearers. Corneal epithelial thickness can change in response to underlying corneal stromal changes to reduce corneal irregularity in response to various conditions and pathologies, including contact lenses and KC[23]. The increase of the flattest keratometric values may result from corneal epithelial remodeling, affected by contact lenses[23-24]. Meanwhile, the effect of RGP-CL on KC patients has been studied in many aspects, including the changes of cell area, density, pleomorphism, corneal stroma and nerve. The density of corneal endothelium, coefficient of variation and the proportion of hexagonal cells had no statistical differences between RGP wearers and non-wearers in KC patients[25].

In KC, the epithelium is known to thin in the coverage of the cone, and in advanced KC, there may be excessive epithelial thinning resulting in corneal epithelial rupture[26]. Jinabhai *et al*[27] found that wearing RGP-CL had only marginal effects on the thinnest corneal thickness. In this study, the mean thinnest corneal and epithelial thicknesses of the two groups were similar. A localized zone of epithelial thinning surrounded by an annulus of thickened epithelium over the region of the cone (donut shape) was previously reported in KC[28]. In this study, there were no significant differences in the corneal thickness topography and epithelial thickness topography. Nevertheless, given the few serious subjects, the complementation of distributions of different patients' topographies, the lack of epithelial thicknesses data of these patients at baseline, and the small sample size, further studies are needed to illustrate the marginal differences in epithelial thicknesses between the two groups.

Shokrollahzadeh *et al*[14] studied the HOAs of KC patients with RGP-CL wearing and suggested that the effect of wearing RGP-CL on HOAs in a short period of time was mainly caused by changing the vertical coma. In this study, Z_3^{-1} was smaller in RGP-CL wearers as compared to non-wearers in 3.0, 5.0, 6.0, and 7.0 mm pupil diameters, respectively, while there were no significant differences between the two groups in other aberrations including Z_3^1, Z_3^{-3}, and Z_3^3. Similarly, comparison of corneal astigmatism (P=0.714), total HOAs (P=0.079) and Z_4^0 (P=0.827) showed no statistically significant differences between the RGP-CL wearers and non-wearers. Given that the increase of the flattest keratometric values was significantly higher in RGP-CL wearers than non-wearers (P=0.038), and the lower SIf (P=0.004) and BCVf (P=0.047) in RGP-CL wearers, we hypothesized that the reduced Z_3^{-1} was related to relatively uniform distribution of the anterior corneal surface in RGP-CL wearers.

As compared to normal people wearing RGP-CL, KC patients wearing RGP-CL require more attention and follow-up. The NEI-VFQ-25 is a reliable vision-related quality of life assessment questionnaire that is not affected by the types or severities of underlying visual impairments[29]. The conventional psychometric properties and potential weaknesses of the Chinese version of NEI-VFQ-25 are similar to those of the English version[30]. This study found no significant differences in the total score of NEI-VFQ-25 between RGP-CL wearers and non-wearers (P=0.291). The scores of 12 domains were further compared, and no statistically significant difference was found between RGP-CL wearers and non-wearers (P>0.05). Hence, RGP-CL had few effects on the quality of life in KC patients. It should be noted that Chinese prefer to select the middle options when completing questionnaires, which may narrow the difference. The general vision domain had the smallest P-value in the 12 domains, which suggested that wearing RGP-CL might provide better vision for KC patients.

The OSDI can effectively and reliably assess the dry eye condition of the ocular surface and can be a powerful complement to clinical research[31]. This study found no significant difference in the total score of OSDI between RGP-CL wearers and non-wearers. The score of environmental triggering factors was significantly higher in RGP-CL wearers as compared to non-wearers (P=0.003), which may be due to the close relationship between environmental changes and RGP-CL wearing comfort. For RGP-CL wearers, the precorneal tear film is separated into a pre-lens and a post-lens fraction, which results in the disappearance of mucin in the pre-lens part and the loss of lipid in the post-lens part. This separation increases water evaporation and is responsible for the tear film instability. Nevertheless, RGP-CL was reported to have a better OSDI score compared with soft contact lens due to the rigorous length of daily wearing[32].

Woodward *et al*[33] found that diabetic patients have a lower risk of KC, probably due to corneal glycosylation. Meanwhile,

patients with asthma and allergic rhinitis have a higher risk of KC[34-35]. Tréchot *et al*[36] proposed that inflammatory bowel disease may increase the risk of KC and smoking will further increase this risk. KC accompanied with eczema tended to rub their eyes more frequently[37]. Human leukocyte antigens are associated with psoriasis and KC[38]. In this study, none of the 30 patients had a history of diabetes, one patient had asthma, nine patients had allergic rhinitis, five patients had smoking history, five patients had eczema, one patient had psoriasis and one patient had acne, which indicated that the history of systemic disease in Chinese KC patients was consistent with previous studies.

In summary, continuous RGP-CL wearing does not worsen KC. Long-term wearing of RGP-CL causes corneal epithelial remodeling to increase symmetry of corneal anterior surface, reduce corneal vertical coma and improve visual quality. RGP-CL causes a slight decrease in vision-related quality of life. The occurrence of ocular surface symptoms is associated with environmental triggering factors.

ACKNOWLEDGEMENTS

The authors thank all the keratoconus patients who participated in this study.

Authors' contributions: The work was performed in co-operation with all authors. Zhang XF defined research topics and discussed analysis. Wang Y analyzed data, illustrated the results, and drafted the manuscript. Xu Y assisted in performing data collection, statistical analysis, and reference collection. All authors read and approved the final manuscript.

Conflicts of Interest: Xu Y, None; **Wang Y,** None; **Zhang XF,** None.

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