Effects of orthokeratology on biological parameters and visual quality of adolescents with low-grade corneal astigmatism myopia

Q.-H. KONG[1], X.-Y. DU[1], X. LI[2], Z.-Z. WU[3], Z.-L. LIN[1]

[1]Department of Ophthalmology, The First Affiliated Hospital of Shenzhen University, Shenzhen Second People's Hospital, Shenzhen, China
[2]Department of Ophthalmology, Maoming People's Hospital, Maoming, China
[3]Department of Ophthalmology, Sichuan Academy of Medical Sciences, Sichuan People's Hospital, Chengdu, China

Abstract. – OBJECTIVE: To investigate the effects of orthokeratology on biological parameters and visual quality of adolescents with low-grade corneal astigmatism myopia.

PATIENTS AND METHODS: In this study, a total of 41 myopic adolescents were prescribed with orthokeratology glasses in our hospital from February 2018 to March 2019 and voluntarily cooperated with relevant examinations before and after wearing orthokeratology lenses. Patients' uncorrected distant visual acuity (UCVA-D), uncorrected near visual acuity (UCVA-N) and naked eye near stereoacuity before wearing glasses, 1 month, and 3 months after wearing glasses were observed. The corneal astigmatism of patients was observed. The corneal endothelial cell density was observed. The dynamic adjustment function (NP, AF, NRA, PRA) values of patients were observed. The comparison of biological indexes in different time periods was observed. The changes of corneal curvature before wearing orthokeratology lens, 1 month and 3 months after wearing orthokeratology lens were observed.

RESULTS: There were significant changes of patients 1 month after wearing orthokeratology lenses ($p < 0.05$), while there was no significant difference between 3 months after wearing the orthokeratology lenses and 1 month after wearing the orthokeratology lenses ($p < 0.05$). Patients' NCAV-D and UCVA-N were recorded by a conversion method of 5 points. There were differences in the NCVA-D, NCVA-N, naked eye near stereoacuity before, 1 month, and 3 months after wearing glasses ($p < 0.05$). By observing patients' biological indicators and dynamic adjustment, it was found that there were statistically significant differences in NP, AF, BRA and PRA before wearing the glasses, 1 month and 3 months after wearing the glasses ($p < 0.05$).

CONCLUSIONS: The use of orthokeratology can greatly correct myopia patients' vision, improve their stereoscopic vision, control the progression of myopia, and improve their eye regulation, which is of high safety and great short-term effect.

Key Words:
Orthokeratology, Myopia, Low corneal astigmatism, Biological parameters, Visual quality.

Introduction

In recent years, with the wide use of electronic products and the increase of learning tasks, the incidence and the speed of myopia progression among teenagers have gradually increased. Myopia is the most common ophthalmic disease in the world[1]. Recently, there is growing evidence that the prevalence of myopia has increased rapidly in many parts of the world, especially in East Asia and South Asia[2,3]. According to Jung et al[4], the prevalence rate of myopia among 19-year-old males in South Korea was 96.5% in 2010. In Taiwan, from 2010 to 2011, the prevalence rate of myopia among male conscripts aged 18 to 24 was 86.1%[5]. In China, the prevalence rates of myopia among Shanghai and Shandong college students are 95.5% and 86.4%[6,7]. It is estimated that myopia will affect nearly 5 billion people and become a major public health challenge by 2050[8]. Myopia brings more than the inconvenience of wearing glasses in daily life. People often neglect the importance of myopia prevention, especially high myopia and ultra-high myopia. Complications associated with high myopia, such as retinal detachment, macular degeneration, papilla of optic nerve deformation and myopic choroidal neovascularization, may lead to severe and irreversible vision loss[9]. Therefore, the prevention and control of myopia are particularly important.

Corresponding Author: Xiaoyan Dou, MD; e-mail: huitan@email.szu.edu.cn

Orthokeratology is defined as the use of specially designed and fitted hard contact lenses to reshape the cornea. It was first introduced in the early 1960s[10]. It utilizes hard materials to ensure the best oxygen transmission rate[11] and is worn at night to reduce and control myopia. Its correction effect and control effect have been widely verified. Many studies[12-14] have shown that orthokeratology can effectively control the progression rate of juvenile myopia. In the study of Charm et al[15], it is indicated that orthokeratology has become a clinically acceptable and effective treatment method in recent years. This study aims to explore the effect of orthokeratology on biological parameters and visual quality of adolescents with low-grade corneal astigmatism myopia, so as to provide references for future clinicians

Patients and Methods

Clinical Data

A total of 41 cases of myopic adolescents (82 eyes) were prescribed with orthokeratology in our hospital and voluntarily to cooperated to wear orthokeratology lenses from February 2018 to March 2019. The research subjects include 21 males and 20 females. Their age ranged from 8 to 18 (12.2±1.1) years, and the myopia degree ranged from 0.74 D to 5.00 D (2.71±1.04 D). This study has been approved by the Ethical Committee of our hospital.

Inclusion and Exclusion Criteria

Inclusion criteria: patients aged from 8 to 18 years old. Patients with good personal hygiene, living and learning environment. Patients with certain self-care ability and supervision of family members. Patients whose corneal curvature ranged from 7.40 to 8.25 mm. Patients whose astigmatism (astigmatism with rule) was less than -1.50 D. Patients whose myopia progressed rapidly. Patients without active eye disease. Patients with complete general clinical data. Patients themselves or immediate family members signed by the patient or the patients' immediate family.

Exclusion criteria: patients transferred to other hospitals. Patients with history of ocular surgery, trauma, or wearing contact lens wear. Patients complicated with abnormal eye movements and organic eye diseases. Patients accompanied by systemic diseases and congenital neurodevelopmental abnormalities. Patients whose intraocular pressure (IOP) exceeded the normal range.

Detection Methods

Pre-examination: Vision: uncorrected visual acuity (UCVA) was measured with international standard 5 m distance vision chart, and the best corrected vision was measured during optometry. Optometry: After mydriasis, Japanese TOPCON computer corneal optometry KR-800 was utilized. With reference to the results of the computer optometry device, the optometrist would use the optometry group to take the retinoscopy. After the pupil was restored, the optometry was performed again. Finally, subjective pupillary optometry under the pupil was matched to the vision 1.0 result. Corneal topography examination: The anterior segment analysis system (Orbscan II, US) was used for repeated examination for 3 times, and the best quality images were selected for storage and analysis to observe anterior chamber depth and corneal thickness. Corneal endothelial cell examination: Corneal endothelial cell measurement was performed using Japanese Special Microscopep3000P to collect corneal endothelial cell density data. Ocular surface examination: Blink movement, eye movement, palpebral fissure size, eyelash shape and eyelid skin tension were carefully observed. Routine slit lamp examination of aqueous humor, conjunctival inflammation, corneal conjunctival morphology were observed. Fundus examination: Eyelid shape, eyelid skin tension, palpebral fissure size, eyelash shape, eye movement and blink movement were observed. The conjunctiva was observed under slit lamp for signs of congestion, edema, inflammation, purulent secretion and conjunctival calculus. And whether the cornea was smooth and transparent and whether there was abnormality in the fluorescein sodium staining of corneal epithelium were observed. Optometry: Sub-pupillary and mydriatic optometry was performed with a fully automatic computer optometry instrument (ARK-510A, Nidek, Japan), and the final sub-pupillary subjective optometry result was taken as the standard. The values of the dynamic adjustment function [near point of accommodation (NP), adjust sensitivity (AF), negative relative adjustment (NRA) and positive relative adjustment (PRA)] were also checked. Tear secretion test: Schirmer's Test I was used to measure tear volume to exclude xerophthalmia.

Lens Inspection

At the conjunctival point, appropriate amount of fluorescein sodium was added, and the position and activity of the lens were observed under blue light of cobalt slit lamp. The well-fitting lens position should be in the middle or slightly down. When blinking, the lens might move 1-2 mm but it could automatically return to the central position. The middle peripheral cornea was in close contact with the ring between the positioning arcs. The reverse arc and the tear layer between the corneas presented a 360-degree fluorescent ring (with width of about 1 mm). There was no large bubble between the lens and the cornea, the vision of patients after wearing the glasses was ≥ 1.0, and the lens with corresponding parameters should be customized after proper trial wear. All of them were worn at night for 8-10 h/night.

Outcome Measures

Main outcome measures: Patients' uncorrected distant visual acuity (UCVA-D), uncorrected near visual acuity (UCVA-N) and naked eye near stereoacuity before, 1 month, and 3 months after wearing glasses were observed. The corneal astigmatism of patients was observed. The corneal endothelial cell density was observed. The dynamic adjustment function (NP, AF, NRA, PRA) values of patients were observed.

Secondary outcome measures: The comparison of biological indicators in different periods was observed. The changes of corneal curvature before, 1 month and 3 months after wearing orthokeratology lens were observed.

Statistical Analysis

In this study, SPSS 20.0 software package (IBM Corp, Armonk, NY, USA) was used for statistical analysis of the collected data, and GraphPad 7 software package was used to draw the required pictures. Kolmogorov-Smirnov test was used to analyze the distribution of counting data, in which the normal distribution data were expressed as mean ± standard deviation (Meas±SD). Independent sample *t*-test was used for comparison between groups. Intra-group comparison was analyzed using the paired *t*-test. Counting data were expressed by rate (%), qualified by chi-square test and represented by χ^2. When $p<0.05$, there was a statistical difference.

Results

Corneal Curvature

There was no significant difference between the steep k value and the flat k value of the patients before wearing orthokeratology lenses ($p>$ 0.05), while it changed significantly after wearing orthokeratology lenses for 1 month ($p<$ 0.05). And there was no significant difference between 3 months after wearing orthokeratology lenses and 1 month after wearing orthokeratology lenses ($p<$ 0.05), as shown in Figure 1.

Visual Acuity of Patients at Different Time Periods

Patients' NCAV-D and UCVA-N were recorded by a conversion method of 5 points. There were differences in the NCVA-D, NCVA-N, naked eye near stereoacuity before wearing glasses and 1 month, 3 months after wearing glasses ($p<0.05$). After wearing 3 months of glasses, both UCVA-N and ICVA-D were higher than that of 1 month, and both UCVA-N and ICVA-D of patients wearing glasses for 1 month were higher than that of the before wearing glasses ($p<$ 0.05). After wearing 3 months of glasses, naked eye near stereoacuity was lower than that of 1 month, and naked eye near stereoacuity of patients wearing glasses for 1 month was lower than that of the before wearing glasses ($p<$ 0.05; Table I).

Corneal Astigmatism

Before and after wearing the orthokeratology lenses, the corneal astigmatism value of the patient was obtained through corneal topography. Univariate repeated measures of variance were performed, F (2.00,120.00) = 0.07, p= 0.993. It was found that there was no significant difference before wearing orthokeratology lenses and 1 month, 3 months after wearing orthokeratology lenses. Both P values of pairwise comparisons were significantly greater than 0.05, as shown in Table II.

Density of Corneal Endothelial Cells

Univariate repeated measures of variance of corneal endothelial cell density in all patients before and after wearing the orthokeratology lenses was performed, F (2.000,120.000) =0.108, $p>$ 0.05. Both p-values of pairwise comparisons were significantly greater than 0.05. There was no significant difference in the density of anterior corneal endothelial cells before and after wearing orthokeratology lenses, as shown in Table III.

Dynamic Adjustment Function

There were statistically significant differences in NP, AF, BRA and PRA before wearing the glasses and 1 month, 3 months after wearing the

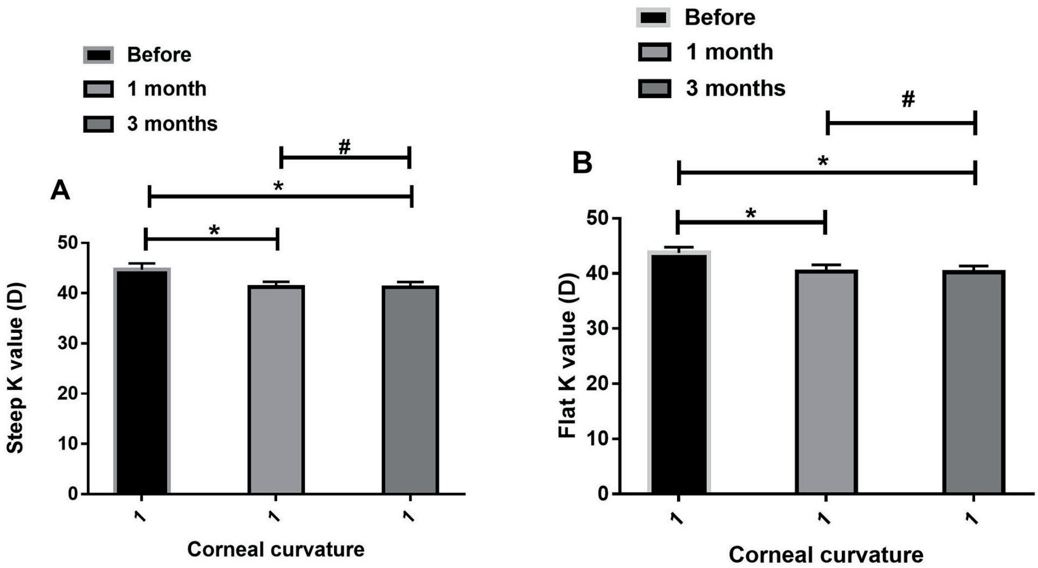

Figure 1. Corneal curvature. **A,** Steep K value The curvature of the central cornea changed significantly before and after wearing the orthokeratology lens. The steep K value changed significantly after wearing OK lens for 1 month (p<0.05). There was no significant difference in the steep K value between wearing OK lens for 3 months and wearing OK glasses for 1 month (p> 0.05). **B**, Flat K value The curvature of the central cornea changed significantly before and after wearing the orthokeratology lens. The flat K value changed significantly after wearing the OK lens for 1 month (p<0.05). and after 3 months wearing the OK lens There was no significant difference in the flat K value between wearing OK lens for 3 months and wearing OK glasses for 1 month (p> 0.05). Notes: # indicates that there is no difference between the two groups (p> 0.05), and * indicates that there is a difference between the two groups (p< 0.05).

Table I. Visual acuity of patients at different time periods.

Time	UCVA-D (points)	UCVA-N (points)	Naked eye near stereoacuity (points)
Before wearing glasses	3.81±0.13	4.03±0.12	254.15±64.19
1 month after wearing glasses	4.30±0.14	4.37±0.11	167.12±31.09
3 months after wearing glasses	4.75±0.18	4.92±0.15	126.17±28.34
F	394.600	506.300	89.220
p	0.001	0.001	0.001

Table II. Comparison of corneal astigmatism before and after wearing orthokeratology lenses ($\bar{x} \pm s$) (Unit: D).

	Mean (x)	Standard deviation (s)
Corneal astigmatism value before wearing orthokeratology lenses	-1.174	0.398
Corneal astigmatism value after wearing orthokeratology lenses for 1 month	-1.188	0.564
Corneal astigmatism value after wearing orthokeratology lenses for 3 months	-1.183	0.612

glasses (p< 0.05). Pairwise comparison indicated that after wearing 3 months of glasses, both NP and NRA were lower than that of 1 month, and this data after wearing glasses for 1 month was lower than that before wearing glasses (p< 0.05). After wearing 3 months of glasses, both AF and PRA were higher than that of 1 month, and the data after wearing glasses for 1 month was higher than that before wearing glasses (p< 0.05; Table IV).

Comparison of Biological Indicators of Patients

There was no statistical difference in intraocular pressure (IOP), anterior chamber depth, central corneal thickness and axial length before

Table III. Comparison of density of anterior corneal endothelial cells before and after wearing orthokeratology lenses ($\bar{x} \pm s$) (Unit: per/mm²).

	Mean ($\bar{x}$)	Standard deviation (s)
Density of anterior corneal endothelial cells before wearing orthokeratology lenses	3071.430	268.330
Density of anterior corneal endothelial cells after wearing orthokeratology lenses for 1 month	3098.340	266.010
Density of anterior corneal endothelial cells after wearing orthokeratology lenses for 3 months	3081.650	260.800

Table IV. Comparison of dynamic adjustment function of patients.

Time	NP (cm)	AF (Circuit/min)	BRA (φ/D)	PRA (φ/D)
Before wearing glasses	9.12±1.63	8.65±2.02	+2.62±0.23	-2.19±0.25
1 month after wearing glasses	7.59±1.12	9.38±2.17	+2.37±0.36	-2.60±0.41
3 months after wearing glasses	6.62±0.75	10.18±2.23	+2.15±0.32	-2.94±0.45
F	43.680	5.234	23.870	40.050
p	0.001	0.007	0.001	0.001

wearing the glasses and 1 month, 3 months after wearing the glasses ($p > 0.05$; Table V).

Discussion

Myopia is one of the most common eye diseases and is becoming increasingly common in adults and children[16,17]. Myopia is now widely recognized as an important public health problem, leading to severe vision loss. High myopia is associated with increased risk of retinal and vitrectomy detachment, glaucoma and macular degeneration, and increased medical costs and eye-related morbidity[18]. The prevalence of this disease is on the rise globally for reasons that are unclear[19]. Therefore, many approaches have been implemented to try to slow down or stop the development of myopia in children[20]. These methods are generally divided into two broad categories: topical application of tropicamide, atropine, pirenzepine, or certain IOP-lowering medication, as well as optical therapy, such as hard contact lenses, bifocals, or multi-focus glasses[21-23]. Orthokeratology is an alternative to correcting refractive errors by temporarily modifying the corneal curvature using custom-designed hard lenses. The working mechanism of orthokeratology lies in the inverse geometry design. The base arc area is flat. The reverse arc area forms negative pressure in the tear fluid, which makes the central corneal area flat, and part of the corneal tissue migrates to the inverted arc area. While correcting the diopters in the central cornea, myopia defocus is formed in the central and peripheral cornea, thereby controlling the development of myopia[24].

The correction of myopia with orthokeratology depends mainly on the corneal curvature. In this study, we first compared the corneal curvature of the patient, and the results showed that the curvature value of the central cornea significantly

Table V. Biological indicators.

Time	IOP (mmHg)	Anterior chamber depth (mm)	Central corneal thickness (μm)	Axial length (mm)
Before wearing glasses	15.62±2.71	3.03±0.14	542.07±33.01	26.70±1.06
1 months after wearing glasses	15.34±2.24	3.09±0.12	535.13±31.16	26.58±1.03
3 months after wearing glasses	15.18±2.19	3.05±0.18	531.27±28.64	26.41±1.02
F	0.356	1.729	1.279	0.810
p	0.702	0.182	0.282	0.447

changed after wearing the orthokeratology lenses, and both the steep K value and the flat K value significantly decreased after wearing the orthokeratology lenses for 1 month ($p < 0.05$). However, after wearing the orthokeratology lenses for 3 months, there was no significant difference in either steep K value or flat K value compared with wearing the orthokeratology lenses for 1 month, suggesting the myopia of the patient gradually improved and stabilized. We further observed the visual acuity of the patients at different time periods and found that the UCVA-N and UCVA-D increased gradually after wearing the glasses for 1 month and 3 months, and the naked eye near stereoacuity decreased gradually. According to study of Yoon et al[25], the follow-up morphology of the corneal posterior surface of the patient after wearing the orthokeratoscope for the first 14 days was conducted. It was found that in the process of the myopic power decreased from -2.64 ± 0.99 D to -0.39 ± 0.49 D, there was no significant change in the curvature radius of the corneal apex on the posterior surface, while the aspheric coefficient Q on the posterior surface changed significantly. This indicated that the remodeling of the cornea was mainly on the front surface of the cornea rather than the entire cornea during the initial period of wearing. In this study, we made statistics on the corneal astigmatism value while shaping the cornea with orthokeratology lesnses, and found that there was no obvious change in the corneal astigmatism value at three time points. We preliminarily estimated that the corneal astigmatism value of the orthokeratology lens has no obvious change when using the spherical equivalent to achieve astigmatism correction in a non-real sense. However, under the action of the orthokeratology lenses, the uneven migration of corneal tissue would increase the composition of its irregular astigmatism without changing the composition of its regular astigmatism. Cheung et al[26] also indicated that changes in corneal astigmatism did tend to remain largely unchanged. We observed the dynamic adjustment function and found that there were significant differences in NP, AF, BRA and PRA before wearing glasses and 1 month, 3 months after wearing glasses, which indicated that orthokeratology treatment could enhance the patients' eye adjustment ability and increase the patients' eye adjustment sensitivity, as well as adjustment reserve ability and weaken the eye adjustment relaxation ability.

We have preliminarily proved the effect of orthokeratology on juvenile myopia patients with low corneal astigmatism and visual quality through the above research. However, there are still some certain limitations in this research. First of all, we only carried out short-term experiments, during which time the safety and effectiveness of orthokeratology are affirmed, but the long-term safety, control effect and related biological parameters need to be further verified. Therefore, we hope to extend the experiment time in future studies to supplement our results.

Conclusions

Orthokeratology can greatly correct myopia patients' vision, improve their stereoscopic vision, control the progression of myopia, and improve their eye regulation, which is of high safety and great short-term effect.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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