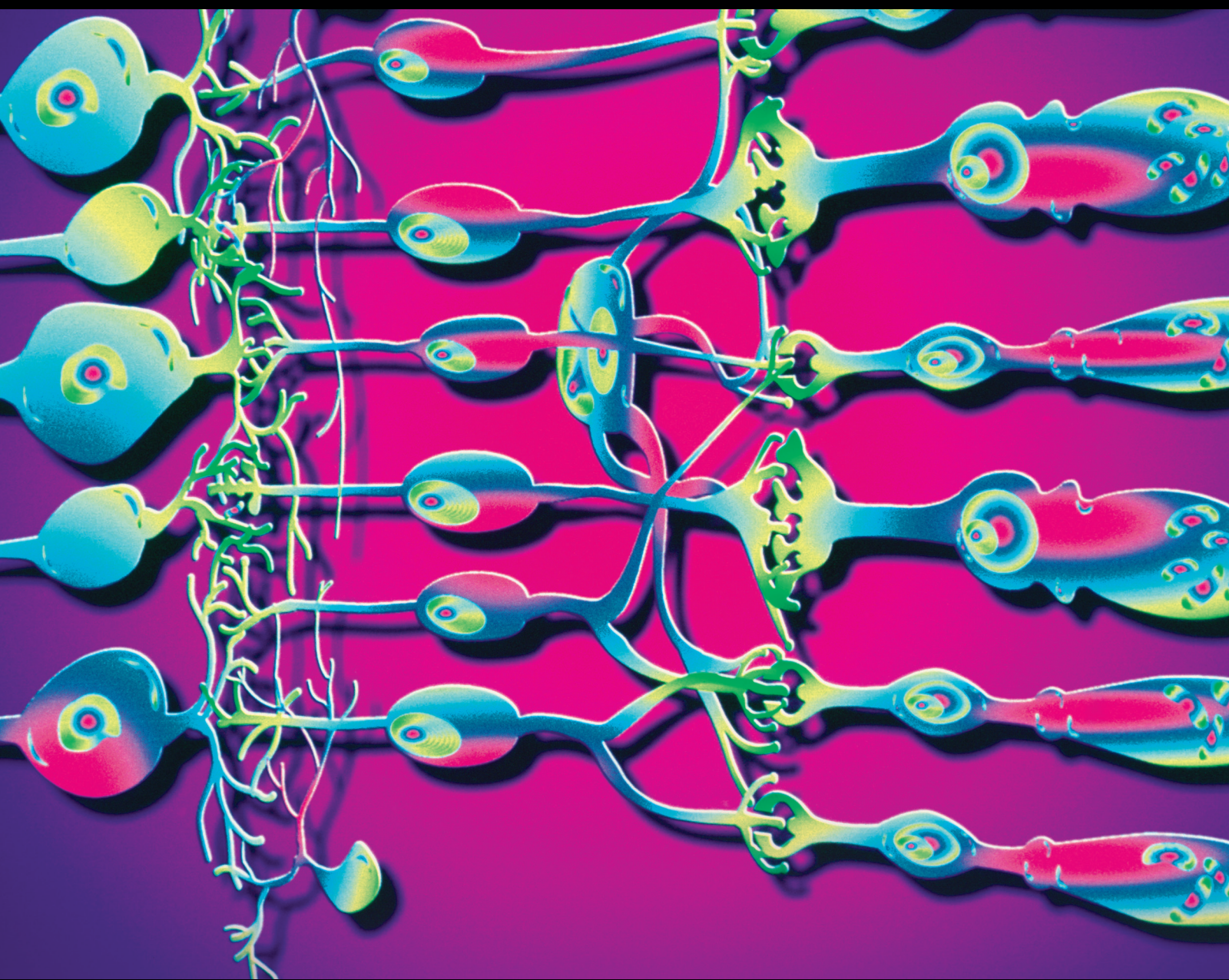
Journal of Ophthalmology

Overnight Orthokeratology: Technology, Efficiency, Safety, and Myopia Control

Lead Guest Editor: César Villa-Collar
Guest Editors: Gonzalo Carracedo, Zhi Chen, and José M. Gonzalez-Méijome



Overnight Orthokeratology: Technology, Efficiency, Safety, and Myopia Control

Journal of Ophthalmology

Overnight Orthokeratology: Technology, Efficiency, Safety, and Myopia Control

Lead Guest Editor: César Villa-Collar
Guest Editors: Gonzalo Carracedo, Zhi Chen, and José M. Gonzalez-Méijome

Editorial Board

Contents

Hindawi
Journal of Ophthalmology
Volume 2019, Article ID 2607429, 2 pages
https://doi.org/10.1155/2019/2607429

Editorial

Overnight Orthokeratology: Technology, Efficiency, Safety, and Myopia Control

César Villa-Collar,[1] **Gonzalo Carracedo**,[2] **Zhi Chen**,[3] **and José M. Gonzalez-Méijome**[4]

[1]*Department of Pharmacy, Biotechnology, Nutrition, Optics and Optometry, Faculty of Biomedical and Health Sciences, Universidad Europea de Madrid, Madrid, Spain*
[2]*Department of Optics II (Optometry and Vision), Faculty of Optics and Optometry, Universidad Complutense de Madrid, Madrid, Spain*
[3]*Department of Ophthalmology and Vision Science, Eye and ENT Hospital, Fudan University, Shanghai, China*
[4]*Clinical & Experimental Optometry Research Lab (CEORLab), Center of Physics, Universidade do Minho, Braga, Portugal*

Correspondence should be addressed to César Villa-Collar; cesar.villa@universidadeuropea.es

Received 28 February 2019; Accepted 28 February 2019; Published 8 April 2019

Modern orthokeratology differs significantly from the original technique back in the 1960s. Over the last 3 decades, new materials, lens designs, manufacturing processes, fitting techniques, and instruments for the analysis of corneal changes have been developed and have contributed to its evolution. Nowadays, orthokeratology is carried out using the contact lenses during sleep hours (overnight orthokeratology (OOK)), and it is approved by FDA for the treatment of myopia, up to 6 dioptres. There are reports of some designs that allow treatment of myopia up to 10–12 dioptres and hyperopia up to 3 dioptres, and recent toric designs, either in the optical zone or in the periphery of the lens, allow correction of astigmatism above 1.75 dioptres up to 3.50 dioptres though those treatments are performed off-label. Currently, even some cases of presbyopia may be solved with the help of OOK [1, 2]. However, the greatest impact of this technique in recent years is its application as a method for the control of myopia progression, either on its own or in combination with low-dose atropine [3, 4]. Recently, a published report written by the American Academy of Ophthalmology concludes that orthokeratology is effective for myopia control and potentially has a greater effect when it is applied in patients aged 6 to 8 years [5].

Moreover, orthokeratology lenses represent 1.2% of all contact lenses fitting operations, although there are significant differences from one country to another, from an almost complete lack of lens fitting in countries like Brazil, Egypt, or Indonesia, up to 6% in the Netherlands. OOK lenses are fitted to younger patients (25.00 ± 12.8 years), as opposed to non-OOK lenses (39.8 ± 14.9 years) [6].

The period from 2013 to 2017 has witnessed a strong increase in the number of published papers regarding this technique, where almost 40% of all the papers about orthokeratology were published over this time period [2]. This is the reason why we suggested *Journal of Ophthalmology* to dedicate a special issue to this contact lens fitting technique.

This special issue contains 6 papers focusing on different aspects, among them, quality of vision, corneal changes according to lens geometry or the involvement of eye surface during their use.

X. Wang et al. consider that OOK influences tear meniscus height and tear break-out time. However, in their opinion, the operation of Meibomian glands is not affected. On the other hand, Z. Chen et al. warn about the increase in corneal toricity after discontinuing the treatment, which is associated with an increase in refractive astigmatism. H.-C. Guo et al. conclude that the OOK reduces the modulation transfer function (MTF) and the contrast sensitivity function (CSF) of low frequencies, as a result of the increase in intraocular scattering as well as higher-order aberrations. Furthermore, CSF values at higher spatial frequencies suffer significant fluctuations one day after the OOK contact lenses

have been used for a whole month. J. Jiang et al. conclude that the design of toric lenses may decrease the size of the off-centring in patients with moderate to high corneal astigmatism. M. A. Sánchez-Tena et al. show the status of the orthokeratology information flow by analysing the so-called citation networks. Finally, G. Carracedo et al. verified that a diameter of 5 mm of the optical area of OOK lenses entails a smaller area of treatment and a greater and more powerful midperipheral ring; in turn, this increases the fourth-order spherical aberration which only affects the CSF, without differences as to visual acuity and subjective vision, when compared with a larger optical zone exceeding 6 mm.

Conflicts of Interest

The authors state that there are no conflicts of interest or private agreements with companies regarding our work for this special issue. The authors have no financial relationships through employment and consultancies, either stock ownership or honoraria, with industry.

César Villa-Collar
Gonzalo Carracedo
Zhi Chen
José Manuel González-Méijome

References

[1] H. A. Swarbrick, "Orthokeratology review and update," *Clinical and Experimental Optometry*, vol. 89, no. 3, pp. 124–143, 2006.

[2] C. Villa-Collar, C. Alvarez-Peregrina, F. Hidalgo Santa Cruz, and F. J. Povedano-Montero, "Bibliometric study of scientific Research on overnight orthokeratology," *Eye Contact Lens*, vol. 44, no. 5, pp. 344–349, 2018.

[3] Q. Tan, A. L. Ng, G. P. Cheng, V. C. Woo, and P. Cho, "Combined atropine with orthokeratology for myopia control: study design and preliminary results," *Current Eye Research*, vol. 11, pp. 1–8, 2019.

[4] Z. Chen, S. Huang, J. Zhou, Q. Xiaomei, X. Zhou, and F. Xue, "Adjuntive effect of orthokeratology and low dose atropine on axial elongation in fast-progressing myopic children—a preliminary retrospective study," *Cont Lens Anterior Eye*, vol. 24, no. 18, pp. S1367–S0484, 2018.

[5] D. K. VanderVeen, R. T. Kraker, S. L. Pineles et al., "Use of orthokeratology for the prevention of myopia progression in children: a report by the American Academy of Ophthalmology," *Ophthalmology*, vol. 23, no. 18, pp. S0161–S6420, 2018.

[6] P. B. Morgan, N. Efron, C. Woods, and J. Santodomingo-Rubido, "International contact lens prescribing survey consortium, "international survey of orthokeratology contact lens fitting," *Contact Lens Anterior Eye*, vol. 15, 2018.

Hindawi
Journal of Ophthalmology
Volume 2019, Article ID 6964043, 6 pages
https://doi.org/10.1155/2019/6964043

Research Article

Current State and Future Trends: A Citation Network Analysis of the Orthokeratology Field

Miguel Angel Sanchez-Tena,[1] **Cristina Alvarez-Peregrina**,[1] **Jose Sanchez-Valverde**,[2] **and Cesar Villa-Collar**[1]

[1]*Faculty of Biomedical and Health Sciences, Universidad Europea de Madrid, Madrid 20822, Spain*
[2]*Clinica Oftalmologica Doctor Lens, Madrid 28009, Spain*

Correspondence should be addressed to Miguel Angel Sanchez-Tena; miguelangel.sanchez@universidadeuropea.es

Received 4 October 2018; Revised 21 December 2018; Accepted 12 February 2019; Published 7 March 2019

Academic Editor: Alejandro Cerviño

Introduction. Citation network analysis is a powerful tool that allows for a visual and objective representation of the past, present, and potential future directions of a research field. The objective of this study is using citation analysis network to analyse the evolution of knowledge in the field of orthokeratology. *Materials and Methods*. The database used in this citation networks analysis study was Scopus. The descriptor used was "orthokeratology" limited to three fields: title, keywords, and/or abstract, analysing the five most cited authors. Only articles cited at least twenty times were used. The computer software used was UCINET with two types of analysis, qualitative and quantitative. *Results*. 27 nodes have been included according to the search and inclusion criteria. In qualitative analysis, based on illustrate results, the relationships among nodes and their positions and connections show how the study of Cho et al. in 2005 is clearly positioned as a central cutoff point in the network. Quantitative analysis reveals the normalized value of the sample and shows how the study of Cho et al. in 2005 presents the highest percentage of input connections. *Conclusions*. This study shows the state of the flow of information in the orthokeratology field by providing links in bibliographic citations from a qualitative and quantitative point of view.

1. Introduction

Orthokeratology is a nonsurgical technique that has evolved in the last two decades, starting as a limited clinical treatment, to become a real alternative to reduce, modify, or eliminate refractive errors.

Nowadays, there is enough evidence on the capability of orthokeratology to slow down myopia and the elongation of the eyeball in children [1]. It is therefore an important topic in current scientific research as evidenced by a recent published bibliometric study [2]. This study highlights the boom in orthokeratology research activity over the past 5 years, as well as the growing interest among the scientific community. However, bibliometric studies have some limitations, and they need to be completed with other kinds of analyses of scientific production as citation networks' analysis.

Citation network analysis is a powerful tool that gives a visual and objective representation of the past, present, and potential future directions of a research field [3]. This kind of analysis gives essential information to identify knowledge gaps, trends, and relationships among scientific research in any topic, being helpful in moving any field forward.

The objective of this study is using citation analysis network to analyse the evolution of knowledge in the field of orthokeratology.

2. Materials and Methods

The database used in this citation networks analysis study was Scopus. The descriptor used was "orthokeratology" limited to three fields: title, keywords, and/or abstract, analysing the five most cited authors. Only articles cited at least twenty times in Scopus were selected.

According to the above criteria, a list was obtained, in which each positive article became a node of the citation network. The number in the list depended on how many times the article had been cited, the most cited articles being on the top of the lists. These data were collected on Excel, including all the references of each article and remarking which of the other positive articles of the list are cited, through the link "who quotes whom."

Using the computer software UCINET, the binary and asymmetric square matrix was defined, being 0 = no cited and 1 = cited. The attributes were defined by author, year of publication, and title. Each one was classified within a category: control of myopia or safety and efficacy.

Once the elaborated matrix was available, qualitative and quantitative analysis started.

Qualitative analysis started with the elaboration of a network graph with a UCINET NetDraw program assistant. The structure of the network is analysed from four grouping measures: clique, N-clique, N-clan, and K-plex.

Clique [4–6] is a subgroup within the graph formed by a set of nodes that have all the possible links between them; usually, each clique is formed by three or more members. For N-clique [4–6], a node is a member of a clique if it is connected to all its members at a distance greater than one. The value two is used in all members of the subgraph that do not need to be adjacent but are reachable by an intermediary. To restrict connectivity through nodes that are not members of the clique, N-clan [4–6] is used in which the relationship is still measured, that is, someone is cited through another, but these citations must be reached by other members of the clique.

K-plex [4–6] analysis shows different visions of substructures of the network since it highlights social circles superimposed. It is a subgraph in which each node is adjacent to all but a certain K number of other nodes. A node has a K value of two if it cites all its members except two of them, eliminating the presence of intermediaries. The grouping measures are complementary, and the combination of them shows a better idea of the structure of the network.

Once grouping analysis was carried out, the breakpoints of the structure of the relationships established are analysed by quantifying the subgroups that are not connected to the rest.

For the quantitative analysis, links are analysed through three measures of centrality, giving the position of the nodes within the network and the structure of the network under study: range, degree of intermediation, and degree of proximity.

Range [4–6] (DEGREE) is the number of direct links that a node has. There is an entry range (times the node receives a link from another) and exit range (times the node sends a link to another). As it is an oriented asymmetric matrix formed by digraphs or pairs of nodes, it quantifies which node is most strongly connected.

The Nrmdegree value indicates the normalized range or percentage of connections that a node has over the total network.

The betweenness degree [4–6] (BETWEENNESS) shows when a node connects other two. The interaction between nonadjacent nodes may depend on others, which implies that they can exercise some control over them. This is important for the analysis of the centrality and the cohesion of the network. If we eliminate a node, we can see clearly whether it is a cutoff point or not, measuring how many times a node interposes among others in its geodetic distance.

The closeness degree [4–6] (CLOSENESS) is the distance of a node with the rest, measuring the geodetic distance of all the nodes. In this way, the closer a node from the others is, the greater the index of centrality will be and the faster it will be able to access the information.

3. Results

All searches were carried out in September 2018.

Table 1 shows the 27 nodes that have been included according to the search and inclusion criteria. They have been classified according to their attributes within one of the established categories.

Figure 1 illustrates results from qualitative analysis, explaining the relationships among nodes and their positions and connections. It shows that Cho et al. [7] is clearly positioned as a central cutoff point in the network. This makes a vulnerable network but not disconnected, as there are links between peripheral nodes.

Another key point in Figure 1 is that there are groups and subgroups within the net, making "subgraphs" with more than three linked nodes. UCINET software, through the relational matrix, found 14 cliques but only one increases to four members. The union of Cho et al. [7] and Chen et al. [16] is the most important subgroup in the network, as these authors share papers and relevance in the orthokeratology field.

To N-clique, there are only two disconnected nodes, Swarbrick [10] and Choy et al. [29]. There are 17 related groups, eight of them having more than nine members. N-clan finds 12 groups, four of them made up of nine members, so N-clan has very similar results to N-clique.

In the K-plex analysis, 139 subgroups were calculated, 29 of them having more than three members. This result provides little information beyond the strong cohesion of the citations in this field and the large number of subgroups overlapping within the network. The presence of Cho [7] is observed in all the subgroups found.

Quantitative analysis reveals the normalized value of the sample Nmdegree (DEGREE). It shows that the study of Cho et al. [7] presents the highest percentage of input connections. Also, the study of Chen et al. [16] is the one with the highest percentage of exit degree, being the one that includes the most articles in its references belonging to the network.

The highest value of betweenness (BETWEENNESS) in our network is the study of Cho et al.[7]. It unites the network and is the cutoff point, structuring the network around it.

The degree of closeness (CLOSENESS) presents very close values among all the components of the network, despite the study of Cho et al. [7] being the most valuable as all values of centrality show still.

Table 1: Attributes network.

Node	Authors	Title	Year	Categories
1	Cho et al. [7]	The longitudinal orthokeratology research in children (LORIC) in Hong Kong: A pilot study on refractive changes and myopic control	2005	Myopia control
2	Swarbrick et al. [8]	Corneal response to orthokeratology	1998	Safety and efficacy
3	Cho and Cheung [9]	Retardation of myopia in orthokeratology (ROMIO) study: A 2-year randomized clinical trial	2012	Myopia control
4	Swarbrick [10]	Orthokeratology review and update	2006	Safety and efficacy
5	Santodomingo-Rubido et al [11]	Myopia control with orthokeratology contact lenses in Spain: refractive and biometric changes	2012	Myopia control
6	Queirós et al [12]	Peripheral refraction in myopic patients after orthokeratology	2010	Myopia control
7	Watt and Swarbrick [13]	Microbial keratitis in overnight orthokeratology: review of the first 50 cases	2005	Safety and efficacy
8	Watt and Swarbrick [14]	Trends in microbial keratitis associated with orthokeratology	2007	Safety and efficacy
9	Charm and Cho [15]	High myopia-partial reduction orthok: a 2-year randomized study	2013	Myopia control
10	Chen et al. [16]	Myopia control using toric orthokeratology (to-see study)	2013	Myopia control
11	Boost and Cho [17]	Microbial flora of tears of orthokeratology patients, and microbial contamination of contact lenses and contact lens accessories	2005	Safety and efficacy
12	Cheung et al. [18]	Asymmetrical increase in axial length in the two eyes of a monocular orthokeratology patient	2004	Myopia control
13	Cho et al. [19]	Practice of orthokeratology by a group of contact lens practitioners in Hong Kong: Part I. General overview	2002	Myopia control
14	Nieto-Bona et al. [20]	Short-term effects of overnight orthokeratology on corneal cell morphology and corneal thickness	2011	Safety and efficacy
15	Nieto-Bona et al. [21]	Long-term changes in corneal morphology induced by overnight orthokeratology	2011	Safety and efficacy
16	Chen et al. [22]	A pilot study on the corneal biomechanical changes in short-term orthokeratology	2009	Safety and efficacy
17	Cheung and Cho [23]	Subjective and objective assessments of the effect of orthokeratology-a cross-sectional study	2004	Safety and efficacy
18	Cho et al. [24]	An assessment of consecutively presenting orthokeratology patients in a Hong Kong based private practice	2003	Safety and efficacy
19	González-Méijome et al. [25]	Pilot study on the influence of corneal biomechanical properties over the short term in response to corneal refractive therapy for myopia	2008	Safety and efficacy
20	Jayakumar and Swarbrick [26]	The effect of age on short-term orthokeratology	2005	Safety and efficacy
21	González-Pérez et al. [27]	Tear film inflammatory mediators during continuous wear of contact lenses and corneal refractive therapy	2012	Safety and efficacy
22	Lum et al. [28]	Mapping the corneal sub-basal nerve plexus in orthokeratology lens wear using in vivo laser scanning confocal microscopy.	2012	Safety and efficacy
23	Choy et al. [29]	Effect of one overnight wear of orthokeratology lenses on tear composition	2004	Safety and efficacy
24	Queirós et al. [30]	Effect of pupil size on corneal aberrations before and after standard laser in situ keratomileusis, custom laser in situ keratomileusis, and corneal refractive therapy	2010	Safety and efficacy
25	Cho et al. [31]	Non-compliance and microbial contamination in orthokeratology	2009	Safety and efficacy
26	Queirós et al. [32]	Quality of life of myopic subjects with different methods of visual correction using the NEI RQL-42 questionnaire	2012	Safety and efficacy
27	Chen et al. [33]	Posterior corneal curvature changes and recovery after 6 months of overnight orthokeratology treatment	2010	Safety and efficacy

4. Discussion

Through qualitative analysis, it is proved that the net is not disconnected, although there is a very strong cutoff point in Cho et al. [7]. Just looking to the graph, we can observe that the net is not very dense and that the paper of Cho et al. [7] is the most strongly connected to others and has the most central position.

Regarding citation structure and cohesion, it is noted that the paper of Cho is the one with more shared cliques in all the measures, being the only cutoff point in the network.

N-clique values show just two papers disconnected, which indicates cohesion across the net. This is because orthokeratology is a very specific field, and all papers tend to mention other articles related to their subject of study. N-clan reinforces the cohesion data of the network, sharing very similar results with N-clique. However, they complement each other, ensuring that these articles maintain a direct relationship.

K-plex continues to highlight the presence of Cho et al. [7] in all the groups what can be understood by the small number of articles included. This makes even clearer the great relevance that this article had in the development of orthokeratology.

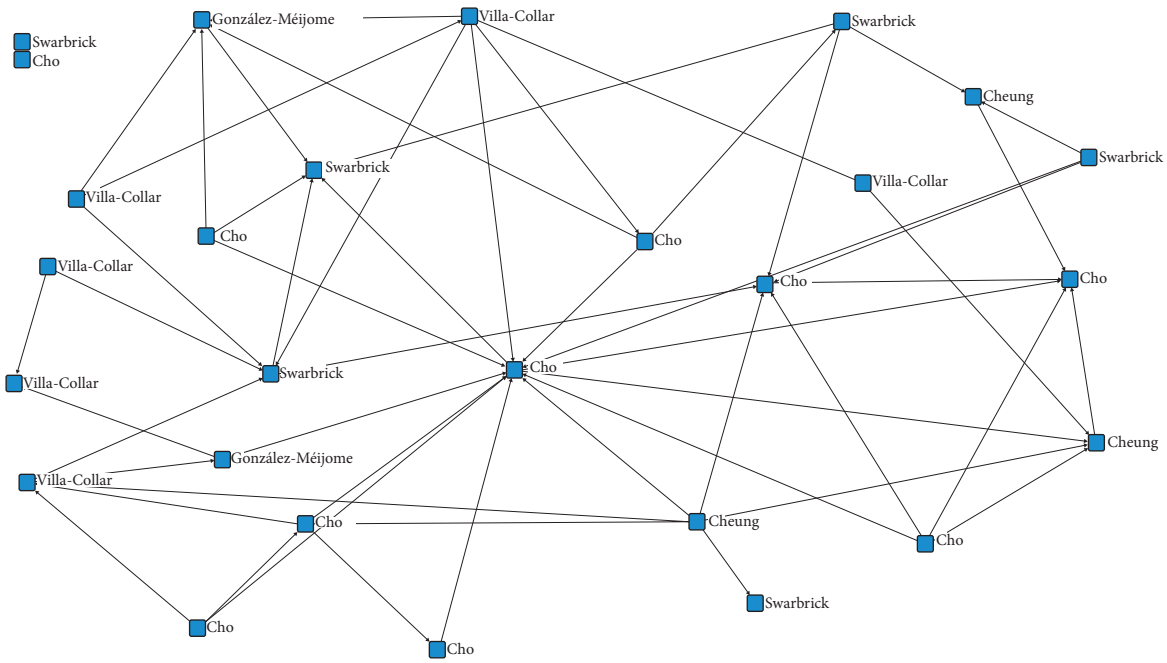


Figure 1: Network graph.

The numerous groupings within a very little dense network again indicate a great cohesion. Despite this low density, this kind of analysis reveals the uniformity in the publications related to orthokeratology and the common criteria that authors follow within it. It also suggests the need in future research for the inclusion of broader cohesion measures in these analyses to avoid biases in the data due to lack of density in the network.

Regarding quantitative analysis, degree of centrality corroborates that the study of Cho et al. [7] has the highest degree of entry and exit cites, ensuring that it is the most relevant and influence article in relation to myopia control and orthokeratology. Its betweenness value compared to other published studies in this field, together with the study Chen et al. [16], makes a binomial of relevance for the topic of control of myopia and orthokeratology. Both have common publications and are the network cutoff point, in addition to being the most relevant subgroup.

In relation to the degree of closeness, it shows that the studies of Cho et al. [19] and Swarbrick et al. [8] are the closest to the others. However, they are very far apart, giving two different visions in the orthokeratology field. On the one hand, we found the articles that look for the topic of control of myopia and on the other hand, those that study the effectiveness of the treatment for the correction of refractive errors.

Analysing in detail all the papers, we found eight studies in the category of myopia control. Six of them have been published in the same institution by Cho et al. [7, 9, 15, 16, 18, 19].

In chronological order, these researchers started writing about their daily clinical experience as leaders in the orthoK field. In 2004, they exposed the results of a study about the influence of orthoK on eye axial length [19]. In 2005, they published the most cited study, LORIC [7], that has become a reference in the use of orthoK as a method to control myopia.

In 2012, Villa-Collar leads MCOS Study [11]. MCOS is like the studies previously cited but carried out in Spain instead of Hong Kong. They analysed refractive and biometric changes.

In relation to the category safety and efficacy, we found 19 papers that met the inclusion criteria, Swarbrick et al. standing out with six papers published by each one [8, 10, 13, 14, 17, 22, 24, 26, 28, 29, 31, 33]. They are followed by Villa-Collar with five papers [20, 21, 27, 30, 32].

Swarbrick et al. is a pioneer with her study in 1998 [8] about corneal response to orthoqueratology. This is in concordance with the data about the degree of closeness.

Later studies of Swarbrick focussed on the incidence of microbial keratitis, with a review and an update about orthoqueratology in 2006 [10].

Villa-Collar focused on studying short- and long-term effects of orthoK on corneal cells morphology, on the effects on tear film, and on quality of life of orthoK wearers versus other methods.

All the papers exposed in this citation network research give a valuable and relevant data that justify that these papers have been the most cited. Most of the researchers are pioneers in publishing papers about different uses of orthoK and about changes in eye and vision produced by orthoqueratology.

5. Conclusions

In conclusion, this study highlights the state of the flow of information in the orthokeratology field by providing links in bibliographic citations from a qualitative and quantitative point of view.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] S. M. Li, M. T. Kang, S. S. Wu et al., "Efficacy, safety and acceptability of orthokeratology on slowing axial elongation in myopic children by meta-analysis," *Current Eye Research*, vol. 41, no. 5, pp. 600–608, 2016.

[2] C. Villa-Collar, C. Álvarez-Peregrina, F. H. S. Cruz, and F. J. Povedano-Montero, "Bibliometric study of scientific research on overnight orthokeratology," *Eye & Contact Lens: Science & Clinical Practice*, vol. 44, no. 5, pp. 344–349, 2018.

[3] J. D. Lecy and K. E. Beatty, "Representative literature reviews using constrained snowball sampling and citation network analysis," *SSRN Electronic Journal*, vol. 27, 2012.

[4] S. Wasserman and K. Faust, *Social Networks Analysis: Methods and Applications*, Cambridge University Press, New York, NY, USA, 1994, ISBN 978-84-7476-631-8.

[5] S. P. Borgatti, M. G. Everett, and J. C. Johnson, *Analyzing Social Networks*, Sage, London, UK, 2013, ISBN 978-1-4462-4740-2.

[6] J. Scott, *Social Network Analysis*, Sage, London, UK, 3rd edition, 2013, ISBN 978-1-4462-0903-5.

[7] P. Cho, S. W. Cheung, and M. Edwards, "The longitudinal orthokeratology research in children (LORIC) in Hong Kong: a pilot study on refractive changes and myopic control," *Current Eye Research*, vol. 30, no. 1, pp. 71–80, 2005.

[8] H. A. Swarbrick, G. Wong, and D. J. O'Leary, "Corneal response to orthokeratology," *Optometry and Vision Science*, vol. 75, no. 11, pp. 791–799, 1998.

[9] P. Cho and S. W. Cheung, "Retardation of myopia in orthokeratology (romio) study: a 2-year randomized clinical trial," *Investigative Opthalmology & Visual Science*, vol. 53, no. 11, p. 7077, 2012.

[10] H. A. Swarbrick, "Orthokeratology review and update," *Clinical and Experimental Optometry*, vol. 89, no. 3, pp. 124–143, 2006.

[11] J. Santodomingo-Rubido, C. Villa-Collar, B. Gilmartin, and R. Gutiérrez-Ortega, "Myopia control with orthokeratology contact lenses in Spain: refractive and biometric changes," *Investigative Ophthalmology and Visual Science*, vol. 53, no. 8, pp. 5060–5065, 2012.

[12] A. Queirós, J. M. González-Méijome, J. Jorge, C. Villa-Collar, and A. R. Gutiérrez, "Peripheral refraction in myopic patients after orthokeratology," *Optometry and Vision Science*, vol. 87, no. 5, pp. 323–329, 2010.

[13] K. Watt and H. A. Swarbrick, "Microbial keratitis in overnight orthokeratology: review of the first 50 cases," *Eye & Contact Lens: Science & Clinical Practice*, vol. 31, no. 5, pp. 201–208, 2005.

[14] K. G. Watt and H. A. Swarbrick, "Trends in microbial keratitis associated with orthokeratology," *Eye & Contact Lens: Science & Clinical Practice*, vol. 33, pp. 373–377, 2007.

[15] J. Charm and P. Cho, "High myopia-partial reduction ortho-k," *Optometry and Vision Science*, vol. 90, no. 6, pp. 530–539, 2013.

[16] C. Chen, S. W. Cheung, and P. Cho, "Myopia control using toric orthokeratology (TO-SEE study)," *Investigative Opthalmology & Visual Science*, vol. 54, no. 10, p. 6510, 2013.

[17] M. V. Boost and P. Cho, "Microbial flora of tears of orthokeratology patients, and microbial contamination of contact lenses and contact lens accessories," *Optometry and Vision Science*, vol. 82, no. 6, pp. 451–458, 2005.

[18] S. W. Cheung, P. Cho, and D. Fan, "Asymmetrical increase in axial length in the two eyes of a monocular orthokeratology patient," *Optometry and Vision Science*, vol. 81, no. 9, pp. 653–656, 2004.

[19] P. Cho, S. W. Cheung, and M. H. Edwards, "Practice of orthokeratology by a group of contact lens practitioners in Hong Kong: part I. General overview," *Clinical and Experimental Optometry*, vol. 85, no. 6, pp. 365–371, 2002.

[20] A. Nieto-Bona, A. González-Mesa, M. P. Nieto-Bona, C. Villa-Collar, and A. Lorente-Velázquez, "Shortterm effects of overnight orthokeratology on corneal cell morphology and corneal thickness," *Cornea*, vol. 30, no. 6, pp. 646–654, 2011.

[21] A. Nieto-Bona, A. González-Mesa, M. P. Nieto-Bona, C. Villa-Collar, and A. Lorente-Velázquez, "Long-term changes in corneal morphology induced by overnight orthokeratology," *Current Eye Research*, vol. 36, no. 10, pp. 895–904, 2011.

[22] D. Chen, A. K. C. Lam, and P. Cho, "A pilot study on the corneal biomechanical changes in short-term orthokeratology," *Ophthalmic and Physiological Optics*, vol. 29, no. 4, pp. 464–471, 2009.

[23] S. W. Cheung and P. Cho, "Subjective and objective assessments of the effect of orthokeratology-a cross-sectional study," *Current Eye Research*, vol. 28, no. 2, pp. 121–127, 2004.

[24] P. Cho, S. W. Cheung, M. H. Edwards, and J. Fung, "An assessment of consecutively presenting orthokeratology patients in a Hong Kong based private practice," *Clinical and Experimental Optometry*, vol. 86, no. 5, pp. 331–338, 2003.

[25] J. M. González-Méijome, C. Villa-Collar, A. Queirós, J. Jorge, and M. A. Parafita, "Pilot study on the influence of corneal biomechanical properties over the short term in response to corneal refractive therapy for myopia," *Cornea*, vol. 27, no. 4, pp. 421–426, 2008.

[26] J. Jayakumar and H. A. Swarbrick, "The effect of age on short-term orthokeratology," *Optometry and Vision Science*, vol. 82, no. 6, pp. 505–511, 2005.

[27] J. González-Pérez, C. Villa-Collar, T. S. Moreiras et al., "Tear film inflammatory mediators during continuous wear of contact lenses and corneal refractive therapy," *British Journal of Ophthalmology*, vol. 96, no. 8, pp. 1092–1098, 2012.

[28] E. Lum, B. Golebiowski, and H. A. Swarbrick, "Mapping the corneal sub-basal nerve plexus in orthokeratology lens wear using in vivo laser scanning confocal microscopy," *Investigative Opthalmology & Visual Science*, vol. 53, no. 4, p. 1803, 2012.

[29] C. K. M. Choy, P. Cho, I. F. F. Benzie, and V. Ng, "Effect of one overnight wear of orthokeratology lenses on tear composition," *Optometry and Vision Science*, vol. 81, no. 6, pp. 414–420, 2004.

[30] A. Queirós, C. Villa-Collar, J. M. González-Méijome, J. Jorge, and A. R. Gutiérrez, "Effect of pupil size on corneal aberrations before and after standard laser in situ keratomileusis, custom laser in situ keratomileusis, and corneal refractive

therapy," *American Journal of Ophthalmology*, vol. 150, no. 1, pp. 97–109, 2010.

[31] P. Cho, M. Boost, and R. Cheng, "Non-compliance and microbial contamination in orthokeratology," *Optometry and Vision Science*, vol. 86, no. 11, pp. 1227–1234, 2009.

[32] A. Queirós, C. Villa-Collar, A. R. Gutiérrez, J. Jorge, and J. M. González-Méijome, "Quality of life of myopic subjects with different methods of visual correction using the NEI RQL-42 questionnaire," *Eye & Contact Lens: Science & Clinical Practice*, vol. 38, no. 2, pp. 116–121, 2012.

[33] D. Chen, A. K. C. Lam, and P. Cho, "Posterior corneal curvature change and recovery after 6 months of overnight orthokeratology treatment," *Ophthalmic and Physiological Optics*, vol. 30, no. 3, pp. 274–280, 2010.

Hindawi
Journal of Ophthalmology
Volume 2019, Article ID 4275269, 9 pages
https://doi.org/10.1155/2019/4275269

Research Article

Comparison of Toric and Spherical Orthokeratology Lenses in Patients with Astigmatism

Jun Jiang,[1,2] Lili Lian,[2] Feifu Wang,[2] Ling Zhou,[2] Xuhong Zhang,[2] and E. Song[1,3]

[1]*Department of Ophthalmology, The Second Affiliated Hospital of Soochow University, Suzhou 215004, China*
[2]*The Affiliate Eye Hospital of Wenzhou Medical University, Wenzhou 325027, China*
[3]*Lixiang Eye Hospital of Soochow University, Suzhou 215021, China*

Correspondence should be addressed to E. Song; songe23@163.com

Received 2 October 2018; Revised 4 January 2019; Accepted 30 January 2019; Published 20 February 2019

Academic Editor: Gonzalo Carracedo

Purpose. This retrospective study aimed at comparing the efficacy and safety of toric and spherical orthokeratology lenses in the treatment of patients with moderate to high astigmatism. *Methods*. Fifty adolescents with myopia and moderate to high astigmatism (≥1.50 D) who underwent consecutive orthokeratology treatment for at least 1 year were included in this study. The toric group comprised 25 subjects (25 eyes, 11 M, 14 F; age, 10.67 ± 1.46 years) who were fitted with toric orthokeratology lenses. The spherical group comprised 25 subjects (25 subjects, 11 M, 14 F; age, 11.45 ± 1.63 years) who were fitted with traditional spherical orthokeratology lenses as a control. Corneal topography, visual acuity, axial length, and slit-lamp examinations were performed to determine the differences between these two groups. The corneal tangential difference mapping was conducted between baseline and every subsequent visit to calculate the magnitude of lens decentration. The corrective effect of ortho-K lens was measured by using the corneal axial difference map. *Results*. The mean decentration and its vertical vector were significantly less in the toric group than in the spherical group after 1 month of lens wear. In toric group, the corneal astigmatism decreased from 1.85 ± 0.31 D at baseline to 1.45 ± 0.85 D after the first month of wear. There was a significant linear correlation between the change in corneal astigmatism and lens decentration in the toric group from 1 month to 1 year ($Y = 3.268 * X + 0.9182$, $R^2 = 0.5035$, $p < 0.0001$ (X: lens decentration; Y: astigmatic changes)). There were no significant differences in the post-OK uncorrected visual acuity, myopia control, or ocular health between the toric and spherical groups. *Conclusion*. The toric orthokeratology lens design can effectively reduce the lens decentration magnitude and CJ180 from 1-month visit to 12-month visit of patients with high or moderate corneal astigmatism. Meanwhile, there was no significant difference in visual acuity, myopia control, and ocular health throughout 12 months. However, the effect of toric lenses on corneal morphology may be susceptible to lens positioning.

1. Introduction

Myopia is considered one of the most common ophthalmological diseases and is associated with blurry distant vision and axial elongation [1, 2]. Myopia has become a global eye health problem. It is estimated that, in 2020, one-third of the world's population (approximately 2.5 billion people) will be myopic [3]. Spectacles, contact lenses, and myopic refractive surgery are three effective methods for correcting myopia. Orthokeratology consists of the application of reverse geometry, rigid contact lenses as a non-surgical treatment for myopia and has been widely used in recent years. Myopia is temporarily corrected through the night wear of lenses that flatten the front surface of the cornea to lessen the overall refractive power of the eye [4, 5]. Another important potential function of orthokeratology is effective control over the progression of myopia [4, 6–9]. Several studies have investigated the efficacy and magnitude of orthokeratology in refractive error correction and myopia control [4–9].

In addition to myopia, a high prevalence of astigmatism has also been reported in juveniles with myopia. Lisa et al. [10] reported that the prevalence of refractive and corneal astigmatism (≥1 D) in white school children in Northern Ireland was 20–24% and 25–29%, respectively. In the United States, children with astigmatism ≥2.00 D account for more

than 20% of the total population [11, 12]. The incidence of astigmatism ≥1.00 D in Asia is approximately 10–20% [13, 14]. Moderate to high astigmatism is known as a relative contraindication to traditional orthokeratology lens fitting because of remarkable lens decentration and poor visual quality. Vinod et al. [15] have shown that greater degrees of corneal astigmatism are predicted to result in greater degrees of lens decentration. Different from the availability of myopia correction, orthokeratology lenses can only correct approximately 50% of corneal astigmatism [16]. Thus, high proportion of corneal astigmatism patients wearing orthokeratology lenses are likely to exhibit excessive residual astigmatism.

Toric orthokeratology lenses are specially designed orthokeratology lenses that adopt a spherical design in the optical zone but a toric design in the reverse curve and/or the alignment curve [17]. The lens and the cornea form a fit in the peripheral area and promote stable lens positioning. Pauné et al. [18] and Chen et al. [17] studied subjects with myopia > −5.50 D and astigmatism >1.25 D to investigate the effect of toric orthokeratology lenses. Similar results were obtained, with a significant reduction in the refractive power (Pauné: 106%; Chen: 81%), refractive astigmatism (Pauné: 85%; Chen: 79%), and corneal astigmatism (only in Chen's study: 44%). Toric orthokeratology lenses are effective for correcting low to moderate myopia with moderately high astigmatism.

In our understanding, toric lenses are considered a desirable choice for correcting myopia with moderate to high astigmatism. However, even if the centric position is established in the outset, the phenomenon of gradual lens decentration is occasionally observed in toric lens wearers in subsequent visits.

Orthokeratology modifies the cornea by its back surface [5]. Diverse back surface designs are likely to play different roles in the progression of corneal reshaping and myopia control. However, there are no published papers comparing the associated corneal changes and myopia progression of the toric design lens and spherical lens.

The primary purpose of this study was to compare the efficacy and safety of the two orthokeratology lens designs in the correction of patients with myopia and moderate to high corneal astigmatism over one year. The results of the study may help in predicting the corrective effects in patients with astigmatism and provide theoretical support for lens selection.

2. Methods and Subjects

2.1. Methods. This was a case-control study including all adolescents who had been fitted for orthokeratology lenses at the Eye Hospital of Wenzhou Medical University between 2014 and 2016. Based on the one-to-one match principle (same age, gender, proximate spherical equivalence, and corneal astigmatism), 25 eyes of 25 subjects were enrolled and included in the toric group and another 25 eyes of 25 subjects were enrolled in the spherical group. A series of regular ocular examinations (uncorrected visual acuity (UCVA), subjective refraction, corneal topography, intraocular pressure and tear break-up time, and axial length) were conducted before fitting the patient with trial lenses. Lens parameter selection was performed by the same experienced clinician. The first orthokeratology trial lenses were determined by the Sim K, and eccentricity values along the flattest meridian were calculated from the Medmont E300 corneal topographer (Medmont Studio 6 software version; Medmont International Pty, Ltd., Victoria, Australia). After a 20-minute trial in the clinic, the fluorescein pattern was evaluated to assess the suitability of the fit. The desired lenses were ordered based on the horizontal visible iris diameter, the fluorescein evaluation, and the over refraction result. Each patient was taught how to insert, remove, and care for the lens by professional clinicians in the hospital and instructed to wear the lens 8–10 hours per night. During subsequent routine visits, the subjects went to the clinic at 8–9 am while wearing the lenses, and the lenses were removed before their eyes were examined. The routine follow-up visits were scheduled at 1 day, 1 week, 1 month, 6 months, and 1 year. Each visit included UCVA measurements, corneal topography, and slit-lamp examinations. And, the axial length was recorded at the 1-year follow-up.

2.2. Subjects. In all, 50 adolescents were included in this study. They underwent orthokeratology treatment for at least one year and participated in regular follow-up visits. The subjects were divided into the toric and spherical lens design groups. Only one eye of each subject was included in this study. If both eyes met the inclusion criteria (Table 1), the right eye was chosen for analysis.

2.3. Orthokeratology Lens. The orthokeratology lenses used in this research were five-zone, reverse-geometry lenses (Lucid, Korea) consisting of Boston XO material ($100 \times 10^{-11}(\mathrm{cm}^2 \cdot \mathrm{mlO}^2)/(\mathrm{s} \cdot \mathrm{ml} \cdot \mathrm{mmHg})$). The lenses were designed with an overall diameter of 10.2–10.8 mm, a central optical zone diameter of 6 mm, and a central thickness of 0.23 mm. The toric lenses adopted a toric design for both the reverse and alignment curves. The lenses were designed according to the Jessen factor principle [19]: the myopia reduction was increased by 1 D per 0.2 mm, and the curvature radius of the orthokeratology lenses was flatter than the flat K value.

2.4. Measurements

2.4.1. Visual Acuity. The monocular visual acuity of each subject was measured after they had picked up the lenses in the morning.

2.4.2. Corneal Topography. Keratometry readings were measured using a Medmont E300 corneal topographer at baseline and every following visit. The corneal topographer is a placido disk-based video keratoscope that can calculate the axial curvature, the tangential curvature, and elevation data through a chord of 9 mm [20].

Table 1: Inclusion and exclusion criteria.

Inclusion Criteria
1. 8 ≤ Age ≤15 at baseline
2. Best-corrected distance monocular visual acuity (BCVA) ≤0.00 logMAR
3. Spherical refractive error(noncycloplegic subjective refraction) ≥−6.00 D
4. With-the-rule corneal astigmatism(noncycloplegic subjective refraction) ≥1.50 D
5. Corneal flat *K* value 41.00 D~46.00 D
6. No orthokeratology fitting contraindication
7. No history of ocular surgery and trauma
8. No history of other contact lens wearing
9. No current systemic or ocular conditions that may affect lens wear
Exclusion Criteria
1. Follow-up irregularly
2. Corneal topography defect 20% or above
3. Change lenses in the follow-up period

2.4.3. Axial Length. The IOL-Master system (IOL-Master, Carl Zeiss, Germany) was used to measure the axial length of the eyeball before and after one year of orthokeratology lens use. Five continuous measurements were conducted, and the average data were automatically calculated for the record.

2.4.4. Slit-Lamp Examination. The ocular health of each subject was evaluated by a specialist doctor. The evaluation included two aspects: an assessment of corneal staining and evaluations of some other ocular adverse reactions, such as corneal pressure and infiltration. For evaluating corneal staining, a fluorescein sodium strip wetted with 0.9% saline was used to touch the lower conjunctiva. The patient was told to blink until the fluorescein was evenly distributed on the corneal surface. The grading scale for corneal staining was as follows: grade 0, no significant corneal staining; grade I, slight scratches or slightly punctate stains; grade II, densely spotted corneal staining with mild discomfort; grade III, small areas of corneal epithelial defects with significant irritation; and grade IV: large areas of corneal epithelial defects with severe irritation.

2.5. Lens Decentration. Corneal tangential difference mapping was conducted between baseline and every visit during the orthokeratology treatment, and the results were analysed by two experienced, independent observers. In the reverse curve, the refractive variation resulting from the orthokeratology treatment showed a tendency to first increase and then decrease. Four maximum plots on the post-orthokeratology astigmatism axis in this region were plotted to simulate an oval. The centre of the oval was defined as the centre of the lens treatment zone. The distance and angle between the apex of the cornea and the centre of the lens treatment zone were then measured, and the decentration was represented by horizontal and vertical vectors after vector decomposition for analysis. All decentered distances are recorded using absolute magnitudes. The accurate positioning method is shown in Figure 1.

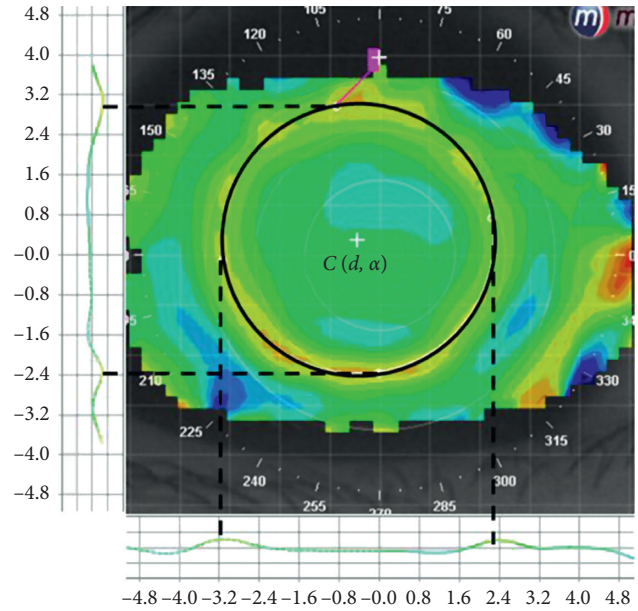


Figure 1: The lens positioning method used in the study.

2.6. Statistical Analysis. SPSS software (version 22.0; IBM, Armonk, NY, USA) was used for the statistical analysis of data in this study. The distribution of the data was analysed using the Kolmogorov–Smirnov normality test. Analysis of variance (ANOVA), Mann–Whitney *U* tests, and chi-squared tests were used to compare the average values between the groups. Repeated measures analysis of variance (RM-ANOVA) and post hoc *t* tests with Bonferroni corrections were used to assess changes in the corneal parameters during the follow-up period. The Greenhouse–Geisser correction was used to correct the experimental results if the significance level of Mauchly's sphericity test result was <0.05. The relations among the parameters involved in this research were analysed by Pearson correlation analysis. The intraclass correlation coefficient (ICC), coefficient of repeatability (COR), and standard deviation (SD) were used to evaluate the repeatability and reproducibility of the experiment, and $p < 0.05$ was considered statistically significant.

3. Results

3.1. Baseline Variables. A total of 50 subjects met the inclusion criteria and were included in this study (toric group: 25 subjects, 10.67 ± 1.46 years; spherical group: 25 subjects, 11.45 ± 1.63 years). There were no significant differences ($p < 0.05$) in the initial parameters between the two groups ($p < 0.05$) (Table 2).

3.2. Repeatability and Reproducibility. The repeatability and reproducibility of the localization method used in this study are shown in Table 3. The SD of three measurements by observers 1 and 2 was 0.030 ± 0.019 and 0.030 ± 0.016, respectively. The COR of the two observers was 7.53% and 8.19%, respectively, while the repeatability coefficient

Table 2: Baseline parameters (mean ± SD) of the two groups.

Parameters	Toric lens group 25 patients, 25 eyes	Spherical lens group 25 patients, 25 eyes	p value
Age (y)	10.67 ± 1.46	11.45 ± 1.63	0.078
Gender (male/female)	11/14	11/14	1.000
Refractive M (D)	−4.01 ± 1.46	−3.64 ± 1.37	0.366
UCVA (logMAR)	0.94 ± 0.32	0.93 ± 0.28	0.866
BCVA (logMAR)	−0.04 ± 0.04	−0.03 ± 0.04	0.779
Axial length (mm)	25.12 ± 0.90	25.01 ± 0.81	0.645
Corneal equivalent power (D)	43.87 ± 1.16	44.01 ± 1.27	0.680
Corneal apical power (D)	43.94 ± 1.19	44.08 ± 1.32	0.696
Corneal toricity (D)	1.85 ± 0.31	1.81 ± 0.32	0.611
Corneal J180 (D)	−0.89 ± 0.16	−0.84 ± 0.17	0.286
Corneal J45 (D)	0.09 ± 0.24	0.05 ± 0.33	0.977

UCVA : uncorrected visual acuity; Corneal J180 = $-C \cos 2\theta/2$; BCVA: best-corrected visual acuity; Corneal J45 = $-C \sin 2\theta/2$ (C: corneal astigmatism power, θ: corneal astigmatism axis).

Table 3: Repeatability and reproducibility of orthokeratology lens decentration measurements.

		SD (mm)	COR (%)	Cronbach's alpha	ICC (95% CI)
For each observer	Observer 1	0.030 ± 0.019	7.25	0.995	0.987 (0.979–0.992)
	Observer 2	0.030 ± 0.016	7.75	0.996	0.987 (0.979–0.992)
Between observers		0.024 ± 0.022	6.51	0.993	0.993 (0.989–0.996)

SD : standard deviation; COV : coefficient of repeatability; ICC : intraclass correlation coefficient.

between the two observers was 7.02%. Cronbach's alpha coefficient and the ICC for each observer and between the observers were both greater than 0.95. Therefore, the use of such a locating method had acceptable repeatability and reproducibility.

3.3. Lens Decentration. The changes in lens decentration over time are presented in Figure 2. There were no significant changes in lens decentration or its decomposed vectors in the toric group over time (RM-ANOVA, $p > 0.20$) (Figure 2(a)). In the spherical group, lens decentration (Figure 2(a)) (post hoc, 1 month versus day 1, $p = 0.008$) and its horizontal vector (Figure 2(b)) (post hoc, 1 month versus day 1, $p = 0.009$) reached a significant increase by 1 month, with no further significant changes throughout the rest of the study period. While the vertical decentration vector in the spherical group increased significantly during the 1-year follow-up (RM-ANOVA, $F = 2.909$, $p = 0.025$, Figure 2(c)), there were no other significant differences among the time points (post hoc, $p > 0.05$). The mean decentration and its vertical vector in the toric group were significantly less than those in the spherical group after 1 month of lens wear and at the later follow-ups (Figure 2(c)). No significant differences were found in the horizontal vector between the two groups (ANOVA, $p > 0.05$, Figure 2(b)).

3.4. Visual Acuity. The UCVA showed significant improvement by the first day (toric group: 0.36 ± 0.31; spherical group: 0.28 ± 0.18) and appeared to stabilize by 1 week (toric group: 0.01 ± 0.08; spherical group: 0.01 ± 0.01 ± 0.08). There was no significant difference between the UCVA measured after one year of wear and the baseline best-corrected visual acuity (BCVA; ANOVA, $p > 0.05$). No significant difference was found in the UCVA between the two groups (ANOVA, $p > 0.05$). The above results could be seen in Figure 3.

3.5. Corneal Topography. The corneal equivalent power and apical power showed significant reductions in both groups over one year of orthokeratology lens wear (RM-ANOVA, $p > 0.001$). The changes reached statistical significance by 1 day and appeared to stabilize by 1 month.

There were no significant differences between the two groups at any follow-up stage (ANOVA, $p > 0.05$). The above results could be seen in Figures 4(a)and 4(b).

The corneal astigmatism in the toric group showed a significant change over one year (RM-ANOVA, $p > 0.020$). The corneal astigmatism decreased from 1.85 ± 0.31 D at baseline to 1.45 ± 0.85 D after the first month of wear and increased to 2.19 ± 1.16 D by 6 months, subsequently decreasing to 2.09 ± 1.39 D by 1 year. There were no significant changes in the corneal astigmatism in the spherical lens group at any visit (RM-ANOVA, $p > 0.234$). Comparison of the corneal astigmatism between the two groups at each follow-up stage showed significantly less astigmatism in the toric group than in the spherical group only after 1 month of orthokeratology lens wear (ANOVA, $p > 0.048$). The above results could be seen in Figure 4(c).

The CJ180 in the toric group decreased significantly overall visits (RM-ANOVA, $p > 0.001$) and decreased by approximately 0.87 D from baseline over 1 year (95% confidence interval: 0.613–1.132 D, post hoc, $p > 0.003$). There were no significant changes in the CJ180 in the spherical group over 1 year (RM-ANOVA, $p > 0.05$). The CJ180 in the toric group was significantly less than that in the spherical group at 1 month, 6 months, and 1 year

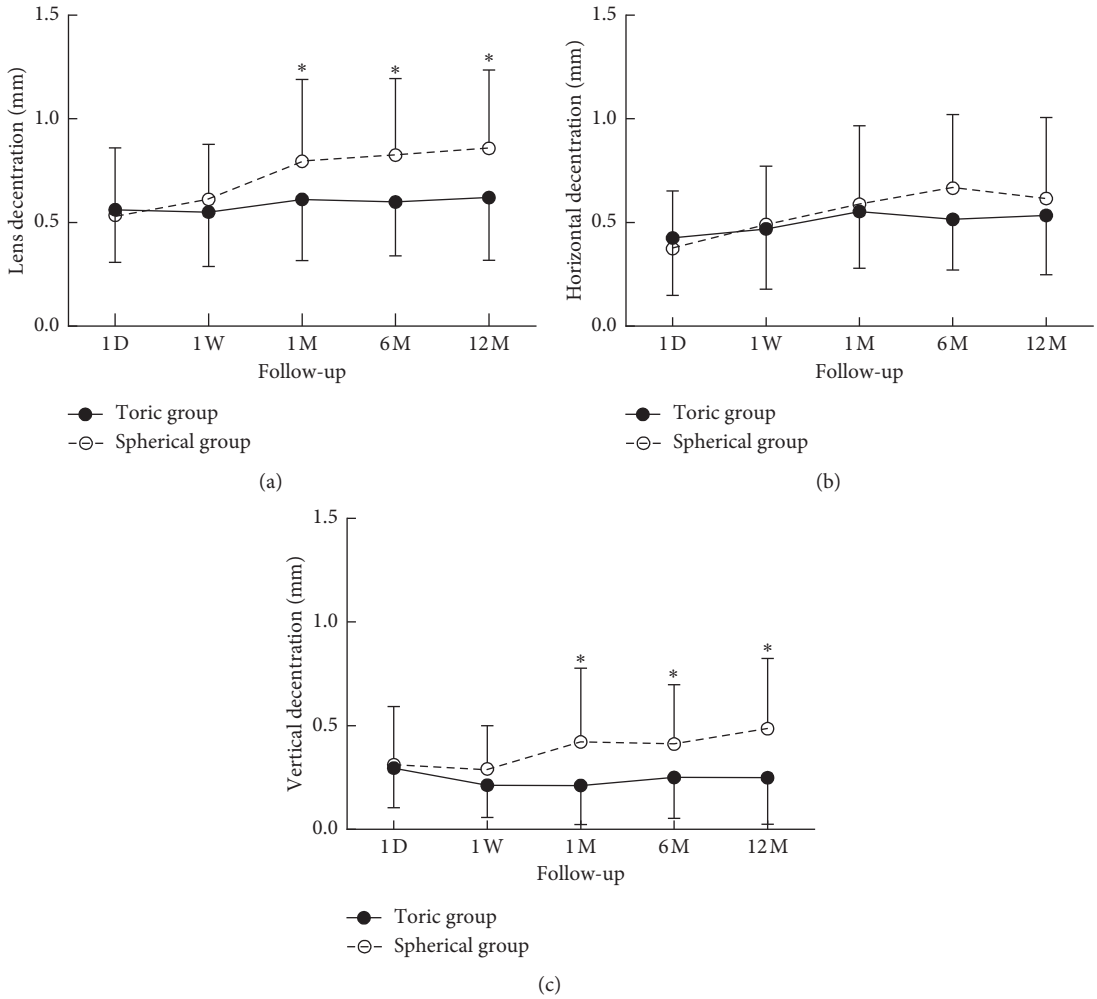


Figure 2: Orthokeratology lens decentration (a) and its horizontal (b) and vertical (c) vectors at all visits over 12 months. The upper and lower error bars represent the SDs for the spherical and toric groups, respectively. *indicates a statistically significant difference between the two groups.

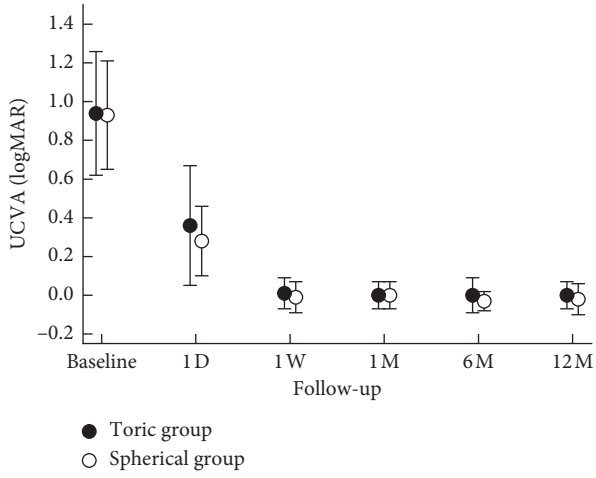


Figure 3: The uncorrected visual acuity (UCVA) for both groups at all visits over 12 months. The error bars represent the standard deviations of the mean value.

(ANOVA, $p > 0.05$). There were no significant changes in the corneal J45 component (CJ45) in the two groups over 1 year (RM-ANOVA, $p > 0.05$), and there were no statistically significant differences between the two groups (ANOVA, $p > 0.05$). The above results could be seen in Figures 4(d) and 4(e).

3.6. Myopia Reduction and Axial Length. The myopia reduction was expressed as a percentage of the initial spherical equivalent power in the change in the corneal apical power based on corneal axial difference map (e.g., initial refraction: $-3.00/-1.00 \times 180$; initial spherical equivalent power: $3.00 + 1.00/2 = 3.50$ D; corneal axial difference map: baseline vs 1 month = 3.00 D; myopia reduction = 3.00/3.50 = 85.71%) [21]. On the first day, the reduction in the toric group was $63 \pm 0.44\%$, which was significantly greater than that in the spherical group, as $39 \pm 0.31\%$ (ANOVA, $p = 0.037$, Figure 5). There was no significant difference

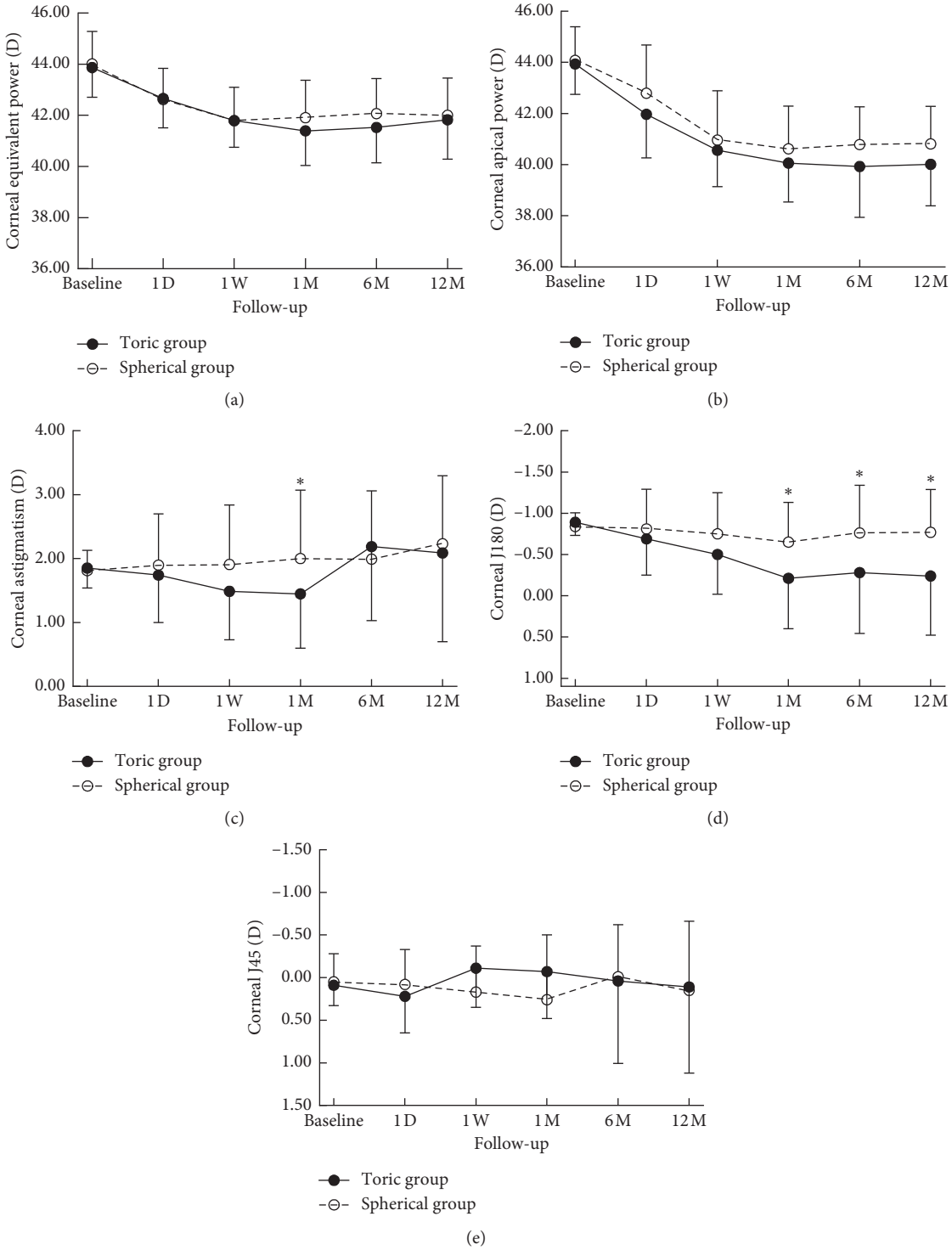


Figure 4: Change of corneal equivalent power (a), corneal apical power (b), corneal astigmatism (c), Corneal J180 (d), and Corneal J45 (e) at all visits over 12 months. The upper and lower error bars represent the standard deviations of the spherical and toric groups, respectively. *indicates a statistically significant difference between the two groups.

between the two groups after 1 week, 1 month, 6 months, or 12 months of lens wear (ANOVA, $p > 0.05$, Figure 5). There was significant linear correction between the myopia reduction and baseline refraction (equivalent spherical power) in both groups (Figure 6). One-way ANOVA was performed to assess changes in the axial length over the 12-month period between the two groups of subjects. The results showed no significant differences in the axial length changes between the two groups (toric group: 0.13 ± 0.18; spherical group: 0.11 ± 0.20, $p > 0.05$).

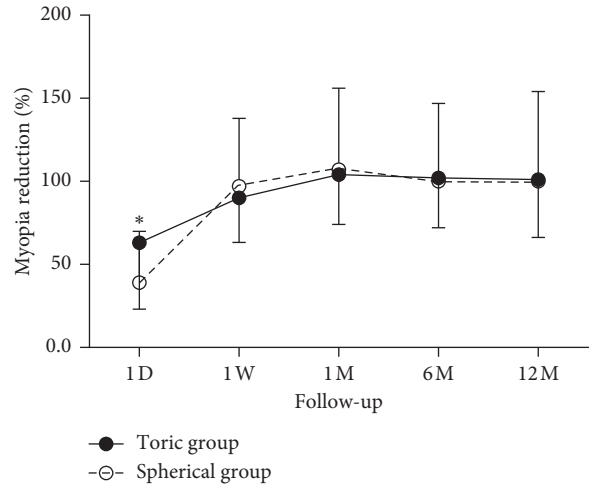


Figure 5: Myopia reduction in the two groups at all visits over 12 months. The upper and lower error bars represent the standard deviations of the spherical and toric groups, respectively. *indicates a statistically significant difference between the two groups.

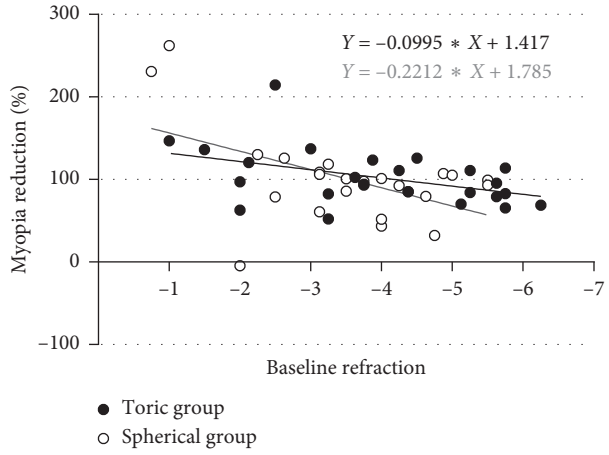


Figure 6: Linear correlation between the myopia reduction and the baseline refraction in the two groups.

3.7. Ocular Health. There were no serious complications, such as corneal infiltration and keratitis, during the study period in either group. Only grade I corneal staining was found in both groups over 1 year. The incidence of spotting in both groups was highest on the first day (toric group: 40%; spherical group: 32%), and there were no significant differences in the incidence of corneal staining between the two groups at various time points (chi-squared test, $p > 0.05$). All corneal staining could be effectively cured by the administration of artificial tears and antibiotic eye drops and not wearing the orthokeratology lenses for a few days. Corneal pressure traces were observed in 3 subjects in each group over 1 year.

4. Discussion

Central and stable lens positioning has always been a sign of successful orthokeratology lens fitting. There have been some previous studies involving the possible influencing factors of spherical orthokeratology lens decentration. Vinod et al. [15] noted that there was a positive correlation between corneal astigmatism and spherical lens decentration, and a negative correlation was found between the corneal curvature and lens decentration. A study by Li et al. [22] showed that the asymmetry of the cornea may be an important cause of lens decentration. In our experiment, there were no significant differences in the above corneal parameters between the two groups at baseline ($p > 0.05$). The difference in lens design might be the main factor affecting lens decentration.

In this study, the lens position showed different trends over time in the two groups. The lens position maintained a steady state in the toric group but showed an increasing trend to decentration in the first month in the spherical group. In other words, significantly less decentration was observed in the toric group than in the spherical group after 1 month of lens wear. The mean difference in the decentration and its horizontal and vertical vectors between the two groups at 1 year was 0.237 mm, 0.082 mm, and 0.236 mm, respectively. The reduced alignment between a spherical lens and toric cornea may be one explanation for this difference. Moreover, the first month is a critical period for corneal reshaping in orthokeratology [23]. Changes in the corneal morphology also lead to dynamic changes in the lens position within 1 month. Due to the toric design of the midperipheral zone, the position of toric lenses may be less affected by the gradual flattening of the central corneal curvature. The toric lenses showed less decentration mainly in the vertical direction, and the spherical lenses showed a tendency towards downward decentration. Previous studies by Vinod et al. [15] and Chen et al. [24] reported a similar result: inferotemporal decentration was most commonly observed in patients with astigmatism wearing spherical lenses. All patients included in this study had with-the-rule astigmatism; thus, the lens was more likely to move up and down with the eyelids. In addition, the effect of gravity on the lens might also be a factor of the above phenomenon.

Numerous previous studies have shown the changes in corneal topography for these two types of lenses at different time points separately. For traditional spherical orthokeratology lenses, most studies have shown that no extra astigmatism was caused in subjects without astigmatism, but the results in patients with astigmatism have been controversial. Cheung et al. [25] conducted a study of spherical lenses in patients with refractive astigmatism of ≤0.75 D for 6 months and found no significant changes in the corneal astigmatism or CJ180 and CJ45 components. Mountford [16] used the Bailey–Carney method combined with the Alpins method to find that spherical lenses can correct approximately 50% of corneal astigmatism. In the case of toric lenses, conclusions obtained from different studies have been consistent: toric orthokeratology lenses can partially correct corneal astigmatism. This study reflects the overall changes occurring over 1 year of wearing two types of lenses, which has not been previously investigated. Absence of

significant changes in corneal astigmatism in the spherical group is consistent with the results obtained by Cheung et al. [25]. The toric group showed two trends over the course of 1 year (the corneal astigmatism decreased from 1.85 ± 0.31 D at baseline to 1.45 ± 0.85 D after the first month of wear and increased to 2.19 ± 1.16 D by 6 months). However, the corneal astigmatism and CJ180 decreased significantly within 1 month, which is consistent with the results obtained by Chen [17] and Pauné [18] in 1 month.

The two lens types showed different trends regarding changes in the corneal astigmatism over one year. The corneal astigmatism was significantly different between the two groups only after 1 month ($p = 0.026$). The corneal astigmatism can be decomposed into the transverse or longitudinal component, CJ180, and the oblique component, CJ45. Only the CJ180 of the toric group showed a significant decreasing trend during the follow-up period and decreased significantly by 73% after 1 year of lens wear. A correlation analysis was performed for the changes in corneal astigmatism, CJ180 and CJ45. The change in corneal astigmatism in the toric group was significantly correlated with the change in CJ180 after 1 month ($R = 0.666$, $R^2 = 0.43$). This correlation was lost after 6 months and 1 year. Moreover, correlation analysis between lens deviation and corneal astigmatism showed a significant linear correlation between the change in astigmatism and lens decentration from 1 month to 1 year. The linear regression equation was $Y = 3.268 * X + 0.9182$, $R^2 = 0.5035$, $p < 0.0001$ (X: lens decentration; Y: astigmatic changes). The significant increase in corneal astigmatism after 1 month can be explained by the following slight decentration. There was no significant correlation between the above two variables in the spherical group.

In this study, the incidence of non-with-the-rule astigmatism was obtained at the different follow-up stages in the two groups, with 12%, 28%, 52% 48%, and 44% in the toric group and 12%, 16%, 16%, 16%, and 24% in the spherical group at 1 day, 1 week, 1 month, 6 month, and 1 year, respectively. The astigmatism in the axial direction in the toric group showed a significant change during lens wear, and the incidence of this change was significantly greater in the toric group than in the spherical group (chi-squared analysis, $p < 0.05$). The change in the astigmatic axis may account for the inconsistency between the corneal astigmatism and CJ180 changes in the toric group after 1 month. The toric lens and the astigmatic cornea form a 360° confined space in the peripheral zone, so the lens misalignment causes morphological changes in the cornea, resulting in additional astigmatism.

The apical corneal power showed a significant linear correlation with the subjective refractive result and was used to calculate the myopia reduction. Although there was no significant difference in visual acuity between the two groups, the toric group showed faster correction and a reduced possibility of temporary central corneal power increase on the first day (Figure 5). The toric orthokeratology lens appeared to show a better corrective effect than the spherical lens in the patients with moderate to high myopia (≤3.00 D) (Figure 5). For patients with high myopia and lower corneal astigmatism, toric orthokeratology lenses can also be actively considered.

Both groups showed acceptable visual acuity and myopia control after 1 year of lens wear. The axial length changes showed myopia control effects similar to those reported by Chen [9] and Pauline [8] et al. The most common adverse reaction in both groups was corneal staining, which is considered reversible and could be cured by short-term treatments. Our results suggest that both orthokeratology lens types can effectively correct myopia in adolescents with moderate to high astigmatism.

5. Conclusion

The toric orthokeratology lens design can effectively reduce the lens decentration magnitude and CJ180 from 1-month visit to 12-month visit of patients with high or moderate corneal astigmatism. Meanwhile, there was no significant difference in visual acuity, myopia control, and ocular health throughout 12 months. However, the effect of toric lenses on corneal morphology may be susceptible to lens positioning.

Data Availability

The data used to support the findings of this study are available from the first author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the Medical and Health Technology Program of Zhejiang under Grant (2018KY542).

References

[1] C. S. Lam, M. Edwards, M. Millodot, and W. S. Goh, "A 2-year longitudinal study of myopia progression and optical component changes among Hong Kong schoolchildren," *Optometry and Vision Science*, vol. 76, pp. 370–380, 1999.

[2] D. O. Mutti, J. R. Hayes, G. L. Mitchell et al., "Refractive error, axial length, and relative peripheral refractive error before and after the onset of myopia," *Investigative Opthalmology & Visual Science*, vol. 48, no. 6, pp. 2510–2519, 2007.

[3] E. Dolgin, "The myopia boom," *Nature*, vol. 519, no. 7543, pp. 276–278, 2015.

[4] P. Cho, S. W. Cheung, and M. Edwards, "The longitudinal orthokeratology research in children (LORIC) in Hong Kong: a pilot study on refractive changes and myopic control," *Current Eye Research*, vol. 30, no. 1, pp. 71–80, 2010.

[5] J. Tsukiyama, Y. Miyamoto, S. Higaki, M. Fukuda, and Y. Shimomura, "Changes in the anterior and posterior radii of the corneal curvature and anterior chamber depth by orthokeratology," *Eye & Contact Lens: Science & Clinical Practice*, vol. 34, no. 1, pp. 17–20, 2008.

[6] J. J. Walline, L. A. Jones, and L. T. Sinnott, "Corneal reshaping and myopia progression," *British Journal of Ophthalmology*, vol. 93, no. 9, pp. 1181–1185, 2009.

[7] T. Kakita, T. Hiraoka, and T. Oshika, "Influence of overnight orthokeratology on axial elongation in childhood myopia," *Investigative Opthalmology & Visual Science*, vol. 52, no. 5, pp. 2170–2174, 2011.

[8] P. Cho and S.-W. Cheung, "Retardation of myopia in orthokeratology (ROMIO) study: a 2-year randomized clinical trial," *Investigative Opthalmology & Visual Science*, vol. 53, no. 11, pp. 7077–7085, 2012.

[9] C. Chen, S. W. Cheung, and P. Cho, "Myopia control using toric orthokeratology (TO-SEE study)," *Investigative Opthalmology & Visual Science*, vol. 54, no. 10, pp. 6510–6517, 2013.

[10] L. O'Donoghue, A. R. Rudnicka, J. F. McClelland, N. S. Logan, C. G. Owen, and K. J. Saunders, "Refractive and corneal astigmatism in white school children in northern ireland," *Investigative Opthalmology & Visual Science*, vol. 52, no. 7, pp. 4048–4053, 2011.

[11] E. M. Harvey, V. Dobson, C. E. Clifford-Donaldson, T. K. Green, D. H. Messer, and J. M. Miller, "Prevalence of astigmatism in Native American infants and children," *Optometry and Vision Science*, vol. 87, pp. 400–405, 2010.

[12] E. M. Harvey, V. Dobson, J. M. Miller et al., "Prevalence of corneal astigmatism in tohono o'odham native American children 6 months to 8 years of age," *Investigative Opthalmology & Visual Science*, vol. 52, no. 7, pp. 4350–4355, 2011.

[13] Y.-F. Shih, C. K. Hsiao, Y.-L. Tung, L. L.-K. Lin, C.-J. Chen, and P.-T. Hung, "The prevalence of astigmatism in Taiwan schoolchildren," *Optometry and Vision Science*, vol. 81, no. 2, pp. 94–98, 2004.

[14] D. S. P. Fan, S. K. Rao, E. Y. Cheung, M. Islam, S. Chew, and D. S. Lam, "Astigmatism in Chinese preschool children: prevalence, change, and effect on refractive development," *British Journal of Ophthalmology*, vol. 88, no. 7, pp. 938–941, 2004.

[15] V. K. Maseedupally, P. Gifford, E. Lum et al., "Treatment zone decentration during orthokeratology on eyes with corneal toricity," *Optometry and Vision Science*, vol. 93, no. 9, pp. 1101–1111, 2016.

[16] J. Mountford and K. Pesudovs, "An analysis of the astigmatic changes induced by accelerated orthokeratology," *Clinical and Experimental Optometry*, vol. 85, no. 5, pp. 284–293, 2002.

[17] C. C. Chen, S. W. Cheung, and P. Cho, "Toric orthokeratology for highly astigmatic children," *Optometry and Vision Science*, vol. 89, no. 6, pp. 849–855, 2012.

[18] J. Pauné, G. Cardona, and L. Quevedo, "Toric double tear reservoir contact lens in orthokeratology for astigmatism," *Eye & Contact Lens: Science & Clinical Practice*, vol. 38, no. 4, pp. 245–251, 2012.

[19] B. Chan, P. Cho, and J. Mountford, "The validity of the Jessen formula in overnight orthokeratology: a retrospective study," *Ophthalmic and Physiological Optics*, vol. 28, no. 3, pp. 265–268, 2008.

[20] Q. Wang, G. Savini, K. J. Hoffer et al., "A comprehensive assessment of the precision and agreement of anterior corneal power measurements obtained using 8 different devices," *PLoS One*, vol. 7, no. 9, Article ID e45607, 2012.

[21] B. Chan, P. Cho, and J. Mountford, "Relationship between corneal topographical changes and subjective myopic reduction in overnight orthokeratology: a retrospective study," *Clinical and Experimental Optometry*, vol. 93, no. 4, pp. 237–242, 2010.

[22] J. Li, C. Yang, W. Xie et al., "Predictive role of corneal Q-value differences between nasal-temporal and superior-inferior quadrants in orthokeratology lens decentration," *Medicine*, vol. 96, no. 2, article e5837, 2017.

[23] A. Alharbi and H. A. Swarbrick, "The effects of overnight orthokeratology lens wear on corneal thickness," *Investigative Opthalmology & Visual Science*, vol. 44, no. 6, pp. 2518–2523, 2003.

[24] Z. Chen, F. Xue, J. Zhou, X. Qu, and X. Zhou, "Prediction of orthokeratology lens decentration with corneal elevation," *Optometry and Vision Science*, vol. 94, no. 9, pp. 903–907, 2017.

[25] S. W. Cheung, P. Cho, and B. Chan, "Astigmatic changes in orthokeratology," *Optometry and Vision Science*, vol. 86, no. 12, pp. 1352–1358, 2009.

Hindawi
Journal of Ophthalmology
Volume 2019, Article ID 5142628, 6 pages
https://doi.org/10.1155/2019/5142628

Clinical Study

The Influence of Overnight Orthokeratology on Ocular Surface and Meibomian Gland Dysfunction in Teenagers with Myopia

Xiu Wang,[1] **Jing Li**,[1] **Rui Zhang**,[1] **Na Li**,[1] **Yi Pang**,[2] **Yan Zhang**,[1] **and Ruihua Wei**[1]

[1]*Tianjin Medical University Eye Hospital, Tianjin Medical University Eye Institute, College of Optometry and Ophthalmology, Tianjin Medical University, Fukang Rd. 251, Nankai District, Tianjin 300384, China*
[2]*Associate Dean for Research, Illinois College of Optometry, 3241 S, Michigan Ave, Chicago, IL 60616, USA*

Correspondence should be addressed to Yan Zhang; yanzhang04@tmu.edu.cn and Ruihua Wei; rwei@tmu.edu.cn

Received 8 May 2018; Revised 20 August 2018; Accepted 14 September 2018; Published 21 January 2019

Academic Editor: Gonzalo Carracedo

Purpose. The aim of this study was to investigate the effect of overnight orthokeratology (OOK) on ocular surface and meibomian gland dysfunction in teenagers with myopia. *Methods*. A total of 59 subjects were recruited in this prospective study. The following tests were performed before and after 1, 3, 6, 12, and 24 months of OOK lens wear, including ocular surface disease index (OSDI) questionnaire, slit-lamp examination, and Keratograph 5M. *Results*. No infectious keratitis occurred during the study. OSDI scores increased gradually and reached the maximum at 6 months of OOK wear ($P < 0.001$). The meniscus height was significantly increased at 1 and 3 months after the initiation of OOK ($P = 0.006$, $P = 0.035$). The corneal fluorescein staining at 1, 3, 6, 12, and 24 months after wearing OOK were all increased than the prewearing level with significant difference ($P = 0.014$, $P = 0.036$, $P < 0.001$, $P < 0.001$, and $P = 0.008$, respectively). The first and the average tear film NIKBUT were all higher than the prewearing level, but there was no significant difference between every follow-up time points ($P > 0.05$). The lid margin abnormalities were significantly increased ($P = 0.003$, $P = 0.038$, and $P = 0.015$) at 6, 12, and 24 months after the initiation of OOK. There was no significant difference in the meibomian gland orifice scores at each follow-up time points compared to the prewearing level ($P > 0.05$). The meibomian gland lipid secretion scores after wearing OOK were higher than those of the prewearing level, however, without statistically significant difference ($P > 0.05$). No significant differences of the degree of difficulty of lipid excretions were detected after the initiation of OOK ($P > 0.05$). There was no significant difference in meibomian gland dropout scores between all follow-up time points and the prewearing level ($P = 1.000$). *Conclusion*. OOK increased the symptoms of dry eye and decreased the function of tear film by affecting the meniscus height and BUT. OOK did not affect the function of meibomian glands.Clinical Study registration number: ChiCTR18000185708.

1. Introduction

Overnight orthokeratology (OOK), an optical compensation mainly for correcting low-to-moderate myopia, is a method to correct refractive errors using custom-designed rigid lenses to temporarily modify the curvature of the cornea [1, 2]. The increased use of OOK is due to its capability to slow down the progression of myopia [3–5]. Recent studies have shown that wearing OOK lenses during nighttime is safe, although they might slightly damage the ocular surface [6, 7]. The effects of OOK on tear film components [8], such as inflammatory mediators [9], have been studied. Several studies have demonstrated that OOK lenses can damage the ocular surface [10–12], and, in serious cases, they can even lead to an infectious corneal ulcer [13].

The purpose of this study was to determine the effects of OOK lens on the ocular surface and meibomain gland over a wearing period of two years in myopic children from 7 to 18 years.

2. Materials and Methods

2.1. Materials. In this prospective study, 59 myopic subjects (average age 12.03 ± 2.31 years, range 7 to 18 years; male to female ratio is 1 : 1.19) were recruited at Tianjin Medical University Eye Hospital (Tianjin, China) from January to

June 2015. Patients with a history of systemic or ocular treatment, contact lens wear, keratitis, ocular allergic disease, any other ocular surface disease, glaucoma, active and chronic uveitis, or previous ocular surgery or injury were excluded. The written informed consent was obtained from the patients' parents. All the procedures and the informed consent form of this study were approved by the Institutional Review Board in Tianjin Medical University Eye Hospital, Tianjin, China. All the procedures performed were in accordance with the tenets of the Declaration of Helsinki.

2.2. Information on Lenses. All participants were fitted empirically with the Emerald™ Contact Lens (oprifocon A, Euclid Systems Corporation, USA). The lenses were fitted in accordance with the manufacturer's guidelines. Ideally, the lens should be fitted in the 3 to 6 mm dark area that is not stained with fluorescein. A 1-2 mm wide fluorescein-filling area is located next to the central reverse arc, and the width of the location arc parallel to the cornea is 2 to 3 mm. The periarc has 0.5 to 1 mm fluorescein filling. There should be a 1-2 mm area for the movement of lens during blinking. After a blink-associated movement, the lens should automatically return to the central cornea. At initial dispense, the lenses were evaluated, and the subjects were trained with the insertion, removal, care, and cleaning of their lenses. Even if the patients reported no changes in visual acuity, the lenses were replaced annually. All procedures for the fitting, prescription, and replacement of OOK lenses were performed by a single experienced specialist. The subjects were provided with O_2 Care Milpha® solution for daily lens cleaning and disinfection and Progent® intensive cleaner for monthly lens cleaning (Menicon Co., Ltd., Nagoya, Japan). The appropriate contact lens fit was accomplished and verified by corneal topography (Orbscan Topography System II; Bausch & Lomb, Salt Lake City, UT). All subjects were asked to sleep uninterruptedly for at least 8 h and remove the lenses immediately upon waking.

2.3. Methods. All subjects were examined by the same experienced examiner before and after 1, 3, 6, 12, and 24 months of OOK lens wear. In each visit, the patients' discomforts were assessed by an ocular surface disease index (OSDI) questionnaire. The ocular surface was examined by Keratograph 5M and a slit lamp. At the final visit, at 24 months after wearing OOK, the incidence of complications was recorded.

2.4. Questionnaire on Dry Eye. The OSDI is valid and reliable for evaluating the severity of dry eye disease, even the dry eye in children [14, 15]. Each subject was asked to complete an OSDI questionnaire for assessment of ocular surface symptoms and the severity of dry eye.

2.5. Slit-Lamp Examinations of the Anterior Segment. The following examinations were carried out sequentially using a slit-lamp: corneal fluorescein staining, lid margin abnormalities, meibomian gland orifices, quality of meibomian gland lipid secretion, and difficulty of lipid excretions.

Corneal fluorescein staining was graded from 0 to 12, which was a sum of the scores of corneal four quadrants. The four quadrants of cornea were carefully examined and scored individually as 0 (no staining), 1 (mild staining with a few scattered dots of stains), 2 (moderate staining between 1 and 3), and 3(severe staining with confluent stains or corneal filaments) [16].

Lid margin abnormalities were scored according to the following 4 signs: vascular engorgement, lid margin irregularity, obstructed meibomian gland orifices, and anterior or posterior displacement of the mucocutaneous junction [17]. The lid margin abnormalities score ranged from 0 to 4.

The quality of meibomian gland orifices was graded semiquantitatively in the central eight glands of the lower right eyelid. Grade 0 is normal, i.e., no obstruction of orifice, and the orifices were covered with a thin and smooth fluid; Grade 1 was obstruction of one or two meibomian gland orifices, or there are secretions or occlusion in one or two meibomian gland orifices; Grade 2 was obstruction of two or three meibomian gland orifices with thick fluid; Grade 3 was obstruction or narrowing of almost half of the meibomian gland orifices; Grade 4 was obstruction or narrowing of more than half of the meibomian gland orifices with sticky secretions.

The quality of meibomian gland lipid secretion was graded semiquantitatively in the central eight glands of the lower right eyelid [18]. Grade 0, clear fluid; Grade 1, cloudy fluid; Grade 2, cloudy, particulate fluid; and Grade 3, inspissated, toothpaste-like fluid.

Difficulty of lipid excretions was graded by squeezing central meibomian gland of the lower eyelid and evaluating the degree of the secretion discharge in the central 5 glands. Grade 0: five glands had secretions out; Grade 1: three to four glands had secretions out; Grade 2: one to two glands had secretions out; Grade 3: no glands had secretions out.

2.6. Keratograph® 5M: Noninvasive Measurement for Ocular Surface. Keratograph® 5M inspection items included noninvasive keratographic tear film break-up time (the first keratographic break-up time and the average keratographic break-up time), noninvasive tear meniscus height, and meibography. The tests were conducted first on the right eye and then on the left. Three measurements were recorded. Keratograph® 5M was used to grade the eyelid using the degree of meibomian gland dropout as meiboscore [17]: Grade 0: no loss of meibomian gland; Grade 1: loss of <1/3 of the whole gland area; Grade 2: loss of 1/3–2/3 of the whole gland area; and Grade 3: loss of >2/3 of the whole gland area. The meiboscore of each eye was calculated as the sum of the scores from both upper and lower eyelids.

2.7. Statistical Analysis. Statistical analyses were performed using Statistical Program for Social Sciences 19.0 (IBM SPSS Inc., New York, NY, USA). No statistically significant difference was found in all parameters between the right and

left eyes. Thus, only the data on the right eyes were used for further analyses. All data were expressed as mean ± standard deviation and tested by D'Agostino and Pearson omnibus normality tests. The data with Gaussian distribution were tested by the Levene test to confirm the homogeneity of variance. The data collected before and after the wearing of OOK lenses were analyzed by two-way ANOVA followed by Tukey's post hoc test. The data with nonparametric distribution were analyzed by the Wilcoxon rank-sum test. P values less than 0.05 were considered significant.

3. Results

The mean spherical equivalent of the subjects was −3.70 ± 1.39 diopter (D). The baseline ocular parameters and subsequent changes at every follow-up time point are presented in Table 1. Allergic conjunctivitis occurred in six subjects. They were instructed to temporarily stop wearing OOK lenses and use 0.1% olopatadine eye drops (Alcon Laboratories, Inc.) at b.i.d. One month after the allergic conjunctivitis was resolved, the subjects resumed OOK lenses. No infectious keratitis was observed during the study period. No subject dropped out during the study.

Compared with the baseline values, OSDI scores for ocular discomfort increased with the wearing of OOK and peaked at the 6-month visit (Figure 1(a), $P < 0.001$, for 6 months vs baseline). OSDI scores began to decline at 12 and 24 months after wearing OOK and had no significant difference with the baseline values ($P = 0.275$, for 12 months vs baseline; $P = 0.947$, for 24 months vs baseline).

The meniscus height was significantly increased at 1 and 3 months after the initiation of OOK (Figure 1(b), $P = 0.006$, for 1 month vs baseline; $P = 0.035$, for 3 months vs baseline). However, no significant differences were detected between the meniscus heights at 6, 12, and 24 months and that at the baseline ($P = 0.190$, for 6 months vs baseline; $P = 0.117$, for 12 months vs baseline; $P = 0.392$, for 24 months vs baseline).

The corneal fluorescein staining at 1, 3, 6, 12, and 24 months after wearing OOK were all significantly increased in comparison to the prewearing level (Figure 1(c), all $P < 0.05$, when vs baseline). However, there was no significant difference among follow-up time points (all $P > 0.05$). Despite the increments in the corneal fluorescein staining, the subjects opted to continue wearing OOK under careful monitoring.

The first tear film keratographic BUT and the average tear film keratographic BUT were higher than the prewearing level, but there was no significant difference among every follow-up time points (Figures 1(d) and 1(e), all $P > 0.05$).

The lid margin abnormalities were significantly exacerbated at 6, 12, and 24 months after the initiation of OOK (Figure 1(f), $P = 0.003$, 6 months vs baseline; $P = 0.038$, 12 months vs baseline; $P = 0.015$, 24 months vs baseline). However, no significant difference was detected between the levels at 1 and 3 months and that at the baseline (Figure 1(f), $P = 0.726$, 1 month vs baseline; $P = 0.885$, 3 months vs baseline).

There was no significant difference in meibomian gland orifice scores at each follow-up time points compared with the prewearing level (Figure 1(g), all $P > 0.05$). meibomian gland orifice scores showed a trendy increase at 1-month after OOK wear with no statistical significance. The meibomian gland secretion scores after wearing OOK were higher than the prewearing score but without statistical significance (Figure 1(h), all $P > 0.05$). There was no significant difference between every follow-up time points (all $P > 0.05$). No significant differences in the degree of lipid excretion were detected among all the time points prior to and after the OOK wearing (Figure 1(i), all $P > 0.05$).

There were no significant differences in meibomian gland dropout scores between all the follow-up time points and the prewearing level (Figure 1(j), all $P > 0.05$).

4. Discussion

Due to the poor coordination of young children, the data reported in this field are limited and often insufficient to evaluate the effect of overnight orthokeratology on ocular surface and meibomian gland dysfunction in the young individuals. In this study, we employed 6 subjective parameters on the functions of ocular surface and meibomian gland, including OSDI questionnaire, corneal fluorescein staining, lid margin abnormalities, meibomian gland orifices, quality of meibomian gland lipid secretion, and difficulty of lipid excretions, as well as 4 objective parameters, including the first keratographic break-up time, the average keratographic break-up time, tear meniscus height, and meibography. The 10 ocular surface parameters in total make the results of the examinations more comprehensive. More importantly, the 4 objective parameters were measured by the noninvasive Keratograph 5M, which to a certain extent overcomes the difficulty in coordination from the young patients and renders the results of our study more precise.

To date, the safety of using orthokeratology has acquired increasing attention. Infectious keratitis has been reported in patients wearing OOK in both case reports and clinical studies [19–21]. However, no infectious keratitis was detected in this study.

Contact lens can cause eye discomfort (CLD). Several factors, including increased evaporation, thinning of tear film, and incomplete blink, have been proposed as the potential causes of CLD [22, 23]. However, OOK does not involve open-eye lens wear, thus influence resulting from evaporation, tear film thinning, and partial blinking may be minimal compared with conventional contact lens wear. OSDI is an indicator of dry eye and OOK subjective symptoms. In our study, a few of the subjects temporarily stopped wearing OOK due to eye discomfort. Forty out of 59 subjects exhibited increased OSDI scores after wearing OOK; however, the scores declined after 6 months, indicating an improved tolerance to OOK with an extension of wearing.

Meniscus height after wearing OOK significantly increased compared with that at the prewearing level, indicating that OOK wearing results in an increase in tear

Table 1: The baseline ocular parameters and subsequent changes in the values at 1, 3, 6, 12, and 24 months after the wearing of OOK.

	Baseline	1 month	3 months	6 months	12 months	24 months
OSDI score	4.81 ± 6.64	7.48 ± 7.74	9.16 ± 9.43	11.40 ± 11.01	8.13 ± 8.19	6.21 ± 6.95
Meniscus heights	0.22 ± 0.06	0.25 ± 0.05	0.25 ± 0.06	0.24 ± 0.06	0.24 ± 0.04	0.24 ± 0.04
Corneal fluorescein staining scores	0.19 ± 0.43	0.54 ± 0.60	0.51 ± 0.63	0.64 ± 0.74	0.73 ± 0.55	0.56 ± 0.53
The 1st keratographic BUT	11.03 ± 5.53	12.49 ± 7.20	11.99 ± 6.84	11.10 ± 6.35	12.37 ± 5.41	11.73 ± 5.33
The average keratographic BUT	13.02 ± 5.39	14.41 ± 6.77	14.16 ± 6.48	13.31 ± 5.81	13.33 ± 5.33	12.49 ± 5.11
Lid margin abnormalities	0.25 ± 0.54	0.41 ± 0.53	0.37 ± 0.55	0.66 ± 0.66	0.58 ± 0.65	0.61 ± 0.61
Meibomian gland orifice scores	0.53 ± 0.82	0.68 ± 0.84	0.47 ± 0.65	0.58 ± 0.70	0.54 ± 0.65	0.53 ± 0.63
Meibomian gland lipid secretion scores	0.31 ± 0.56	0.49 ± 0.65	0.54 ± 0.70	0.56 ± 0.65	0.56 ± 0.65	0.51 ± 0.59
Difficulty of lipid excretions	0.42 ± 0.65	0.66 ± 0.76	0.54 ± 0.68	0.54 ± 0.68	0.54 ± 0.65	0.54 ± 0.65
Meibomian gland dropout scores	0.68 ± 0.51	0.68 ± 0.51	0.68 ± 0.51	0.68 ± 0.51	0.68 ± 0.51	0.68 ± 0.51

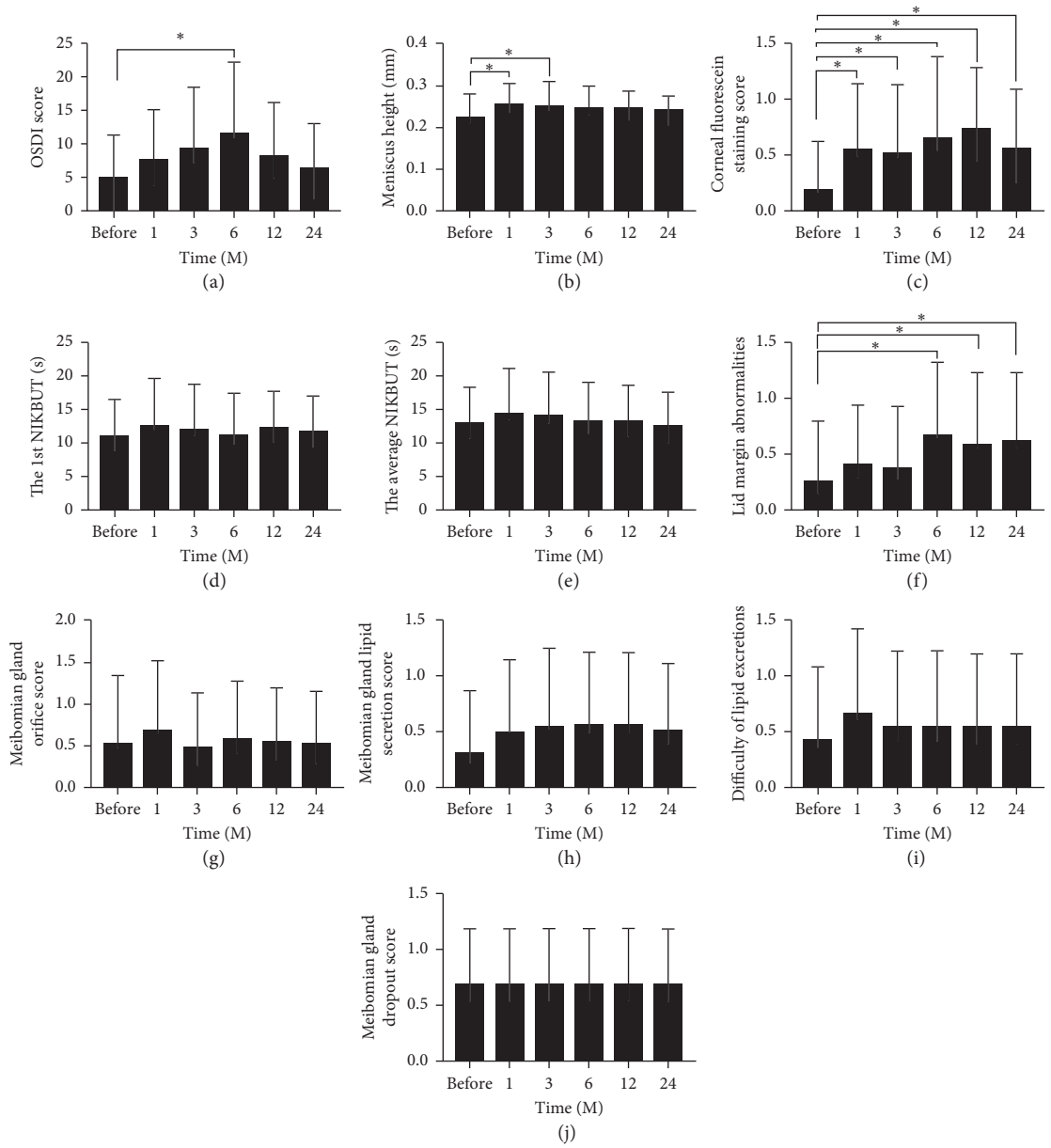


Figure 1: Ocular surface parameters after wearing of OOK. The parameters, including OSDI score (a), meniscus height (b), corneal fluorescein staining score (c), the first keratographic tear film BUT (d), the average keratographic tear film BUT (e), lid margin abnormalities (f), meibomian gland orifice score (g), meibomian gland lipid secretion score (h), difficulty of lipid excretions (i), and meibomian gland dropout scores (j) were compared before and at follow-up time points after wearing OOK. $^{*}P < 0.05$ when compared with prewearing OOK.

secretion. Several studies suggested that OOK, as an eye foreign body, can stimulate excessive tearing [24, 25]. Carracedo's study showed that wearing OOK for 1 month caused no considerable changes in tear function and did not lead to tear-reduction-related symptoms such as dry eye [26]. In this study, after wearing OOK for a month, the OSDI was not significantly different from that at the prewearing level. Moreover, the first tear film keratographic BUT and the average tear film keratographic BUT did not substantially differ among all the follow-up time points.

Although the score of corneal fluorescein staining after wearing OOK was higher than that at the baseline, there was no further increase in the corneal fluorescein staining during the follow-ups. The OOK lenses are composed of rigid and gas-permeable materials with high oxygen permeability. However, long-term wearing still can cause hypoxia to the cornea. Corneal fluorescein staining is the most common complication of OOK lens use [27, 28]. In the study conducted by Li et al., corneal epithelial staining increased after lens wearing with most of the patients graded as I staining and no patient graded more than II [29]. The authors stated that the effect of OOK on the corneal epithelium was minor and reversible [29]. Furthermore, Chan et al. have reported that corneal staining is the most commonly observed complication with OOK; they also suggest that this complication is due to thinning of the central corneal epithelium, improper lens fitting, corneal hypoxia, hypersensitivity to contact lens solution, mechanical abrasion caused by the build-up of deposits on the lens' back surface, lens binding, and incorrect removal of a bound lens in the morning [27]. In our study, subjects were not given artificial tears to prevent corneal staining but were closely monitored for possible changes in the ocular surface. Corneal fluorescence staining score at each follow-up time point was higher than that at the prewearing level, and most patients were at grade I, whereas only 10.52% of the patients reached grade II. No subject's score exceeded grade II.

The indicators of meibomian gland dysfunction (MGD) are lid margin abnormalities, meibomian gland orifice scores, meibomian gland lipid secretion scores, difficulty of lipid excretions, and meibomian gland dropout scores. MGD has recently been considered as a major pathogenic factor for the development of evaporative dry eye, even in children [30]. Loss of meibomian glands is also deemed as a potential cause of CLD [18]. In our study, the meibomian gland dropout maintained its stability after 24 months of wearing OOK, which indicates no observable effect of OOK on the meibomian gland structure. In a previous study, two of the 58 patients with meibomian gland distortion exhibited modification before wearing OOK [12]. Distortion occurred in the first stage of morphologic changes of meibomian glands [31]. Future studies are needed in order to identify subtle meibomian gland changes. Six of the 59 subjects in this study experienced allergic conjunctivitis. The prevalence of allergic conjunctivitis is higher in children compared with adults [32] Numerous children with this condition also suffer from dry eye which complicates the diagnosis of ocular surface disease [33]. In Arita et al.'s study, allergic conjunctivitis is associated with increased meibomian gland duct distortion [34]. Our subjects may have developed subclinical allergic conjunctivitis and distorted meibomian glands at the beginning of the study, and OOK merely aggravated the preexisting allergic conjunctivitis and caused further distortion or loss of the meibomian gland [12].

Our study has limitations. First, this work did not include a control group comprising nonOOK wearers. The ocular surface parameters of postwearing OOK were compared to those of prewearing OOK, instead of those in the nonwearing control subjects. The ocular surface parameters in the nonwearing control subjects may change within the two-year study period. However, this possibility is small when considering the age of the subjects (7 to 18 years old) and the low incidence of dry eye in children. Another limitation is that certain data, such as the parameters on ocular surface and meibomian gland, were subjective. Thus, further studies are warranted to clarify the reversibility of these changes.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

Yan Zhang and Ruihua Wei are co-corresponding authors for this paper.

Conflicts of Interest

The authors have declared that no conflicts of interest exist. The contents of this manuscript have never been published anywhere. This submission is not simultaneously being considered for any other publication.

Acknowledgments

This research was supported by the grants from the National Natural Science Foundation of China (#81770901) and the Tianjin Municipal Science and Technology Commission (#17ZXHLSY00070).

References

[1] P. J. Caroline, "Contemporary orthokeratology," *Contact Lens and Anterior Eye*, vol. 24, no. 1, pp. 41–46, 2001.

[2] T. Dave and D. Ruston, "Current trends in modern orthokeratology," *Ophthalmic and Physiological Optics*, vol. 18, no. 2, pp. 224–233, 1998.

[3] J. Santodomingo-Rubido, C. Villa-Collar, B. Gilmartin, and R. Gutierrez-Ortega, "Myopia control with orthokeratology contact lenses in Spain: refractive and biometric changes," *Investigative Opthalmology & Visual Science*, vol. 53, no. 8, pp. 5060–5065, 2012.

[4] P. Cho and S. W. Cheung, "Retardation of myopia in Orthokeratology (ROMIO) study: a 2-year randomized clinical trial," *Investigative Opthalmology & Visual Science*, vol. 53, no. 11, pp. 7077–7085, 2012.

[5] J. Charm and P. Cho, "High myopia-partial reduction ortho-k: a 2-year randomized study," *Optometry and Vision Science*, vol. 90, no. 6, pp. 530–539, 2013.

[6] R. Mika, B. Morgan, M. Cron, J. Lotoczky, and J. Pole, "Safety and efficacy of overnight orthokeratology in myopic children," *Optometry - Journal of the American Optometric Association*, vol. 78, no. 5, pp. 225–231, 2007.

[7] M. J. Lipson, "Long-term clinical outcomes for overnight corneal reshaping in children and adults," *Eye & Contact Lens: Science & Clinical Practice*, vol. 34, no. 2, pp. 94–99, 2008.

[8] C. K. Choy, P. Cho, I. F. Benzie, and V. Ng, "Effect of one overnight wear of orthokeratology lenses on tear composition," *Optometry and Vision Science*, vol. 81, no. 6, pp. 414–420, 2004.

[9] J. Gonzalez-Perez, C. Villa-Collar, T. Sobrino Moreiras et al., "Tear film inflammatory mediators during continuous wear of contact lenses and corneal refractive therapy," *British Journal of Ophthalmology*, vol. 96, no. 8, pp. 1092–1098, 2012.

[10] K. W. Kam, W. Yung, G. K. H. Li, L. J. Chen, and A. L. Young, "Infectious keratitis and orthokeratology lens use: a systematic review," *Infection*, vol. 45, no. 6, pp. 727–735, 2017.

[11] M. Chunxu, X. Xinyong, and Z. Hui, "Analysis of corneal complications in children wearing orthokeratology lenses at night," *Chinese journal of ophthalmology*, vol. 53, no. 3, pp. 198–202, 2017.

[12] K. S. Na, Y. S. Yoo, H. S. Hwang, J. W. Mok, H. S. Kim, and C. K. Joo, "The influence of overnight orthokeratology on ocular surface and meibomian glands in children and adolescents," *Eye & Contact Lens: Science & Clinical Practice*, vol. 42, no. 1, pp. 68–73, 2016.

[13] M. A. Bullimore, L. T. Sinnott, and L. A. Jones-Jordan, "The risk of microbial keratitis with overnight corneal reshaping lenses," *Optometry and Vision Science*, vol. 90, no. 9, pp. 937–944, 2013.

[14] R. M. Schiffman, M. D. Christianson, G. Jacobsen, J. D. Hirsch, and B. L. Reis, "Reliability and validity of the ocular surface disease index," *Archives of Ophthalmology*, vol. 118, no. 5, pp. 615–621, 2000.

[15] M. Gunay, G. Celik, E. Yildiz et al., "Ocular surface characteristics in diabetic children," *Current Eye Research*, vol. 41, no. 12, pp. 1526–1531, 2016.

[16] A. A. Afonso, D. Monroy, M. E. Stern, W. J. Feuer, S. C. Tseng, and S. C. Pflugfelder, "Correlation of tear fluorescein clearance and Schirmer test scores with ocular irritation symptoms, historical image," *Ophthalmology*, vol. 106, no. 4, pp. 803–810, 1999.

[17] R. Arita, K. Itoh, S. Maeda et al., "Proposed diagnostic criteria for obstructive meibomian gland dysfunction," *Ophthalmology*, vol. 116, no. 11, pp. 2058.e1–2063 e1, 2009.

[18] A. Tomlinson, A. J. Bron, D. R. Korb et al., "The international workshop on meibomian gland dysfunction: report of the diagnosis subcommittee," *Investigative Opthalmology & Visual Science*, vol. 52, no. 4, pp. 2006–2049, 2011.

[19] X. Sun, H. Zhao, S. Deng et al., "Infectious keratitis related to orthokeratology," *Ophthalmic and Physiological Optics*, vol. 26, no. 2, pp. 133–136, 2006.

[20] C. H. Hsiao, L. K. Yeh, A. N. Chao, Y. F. Chen, and K. K. Lin, "*Pseudomonas aeruginosa* corneal ulcer related to overnight orthokeratology," *Chang Gung Medical Journal*, vol. 27, no. 3, pp. 182–187, 2004.

[21] S. Xuguang, C. Lin, Z. Yan et al., "Acanthamoeba keratitis as a complication of orthokeratology," *American Journal of Ophthalmology*, vol. 136, no. 6, pp. 1159–1161, 2003.

[22] J. P. Craig, M. D. Willcox, P. Argueso et al., "The TFOS International Workshop on Contact Lens Discomfort: report of the contact lens interactions with the tear film subcommittee," *Investigative Opthalmology & Visual Science*, vol. 54, no. 11, pp. TFOS123–TFOS156, 2013.

[23] J. J. Nichols, G. L. Mitchell, and P. E. King-Smith, "Thinning rate of the precorneal and prelens tear films," *Investigative Opthalmology & Visual Science*, vol. 46, no. 7, pp. 2353–2361, 2005.

[24] R. Itoh, N. Yokoi, and S. Kinoshita, "Tear film instability induced by rigid contact lenses," *Cornea*, vol. 18, no. 4, pp. 440–443, 1999.

[25] A. Panaser and B. J. Tighe, "Evidence of lipid degradation during overnight contact lens wear: gas chromatography mass spectrometry as the diagnostic tool," *Investigative Opthalmology & Visual Science*, vol. 55, no. 3, pp. 1797–1804, 2014.

[26] G. Carracedo, J. M. Gonzalez-Meijome, and J. Pintor, "Changes in diadenosine polyphosphates during alignment-fit and orthokeratology rigid gas permeable lens wear," *Investigative Opthalmology & Visual Science*, vol. 53, no. 8, pp. 4426–4432, 2012.

[27] B. Chan, P. Cho, and S. W. Cheung, "Orthokeratology practice in children in a university clinic in Hong Kong," *Clinical and Experimental Optometry*, vol. 91, no. 5, pp. 453–460, 2008.

[28] J. J. Walline, M. J. Rah, and L. A. Jones, "The children's overnight orthokeratology investigation (COOKI) pilot study," *Optometry and Vision Science*, vol. 81, no. 6, pp. 407–413, 2004.

[29] J. Li, P. Dong, and H. Liu, "Effect of overnight wear orthokeratology lenses on corneal shape and tears," *Eye & Contact Lens: Science & Clinical Practice*, vol. 44, no. 5, pp. 304–307, 2017.

[30] X. Wang, X. Lu, J. Yang et al., "Evaluation of dry eye and meibomian gland dysfunction in teenagers with myopia through noninvasive Keratograph," *Journal of Ophthalmology*, vol. 2016, Article ID 6761206, 5 pages, 2016.

[31] W. D. Mathers, W. J. Shields, M. S. Sachdev, W. M. Petroll, and J. V. Jester, "meibomian gland dysfunction in chronic blepharitis," *Cornea*, vol. 10, no. 4, pp. 277–285, 1991.

[32] B. Y. Thong, "Allergic conjunctivitis in Asia," *Asia Pacific Allergy*, vol. 7, no. 2, pp. 57–64, 2017.

[33] M. M. Hom, A. L. Nguyen, and L. Bielory, "Allergic conjunctivitis and dry eye syndrome," *Annals of Allergy, Asthma & Immunology*, vol. 108, no. 3, pp. 163–166, 2012.

[34] R. Arita, K. Itoh, S. Maeda et al., "meibomian gland duct distortion in patients with perennial allergic conjunctivitis," *Cornea*, vol. 29, no. 8, pp. 858–860, 2010.

Hindawi
Journal of Ophthalmology
Volume 2019, Article ID 1082472, 10 pages
https://doi.org/10.1155/2019/1082472

Research Article

The Topographical Effect of Optical Zone Diameter in Orthokeratology Contact Lenses in High Myopes

G. Carracedo, T. M. Espinosa-Vidal, I. Martínez-Alberquilla, and L. Batres

Department of Optics II (Optometry and Vision), Faculty of Optics and Optometry, Complutense University of Madrid, Madrid, Spain

Correspondence should be addressed to G. Carracedo; jgcarrac@ucm.es

Received 18 October 2018; Revised 29 November 2018; Accepted 16 December 2018; Published 2 January 2019

Academic Editor: Anna Nowinska

Purpose. To evaluate the effect of the optical zone diameter (OZ) in orthokeratology contact lenses regarding the topographical profile in patients with high myopia (−4.00 D to −7.00 D) and to study its effect over the visual quality. *Materials and Methods*. Twelve patients (18 eyes) were fitted with overnight orthokeratology (OrthoK) with a randomized 6 mm or 5 mm OZ lens worn for 2 weeks, followed by a 2-week washout period, between both designs. Keratometry (K) readings, optical zone treatment diameter (OZT), peripheral ring width (PRW), higher-order aberrations (HOA), high (HC) and low contrast (LC) visual acuity, and subjective vision and comfort were measured at baseline and after 2 weeks of OrthoK lens wear of each contact lens. *Results*. No significant differences were found between any measurements for the same subject at both baselines (p value > 0.05). There was no difference between OZ lens designs found in refraction, subjective vision or comfort, and HC and LC visual acuity. Contrast sensitivity was decreased in the 5 mm OZ lens design compared with 6 mm OZ design (p-value < 0.05). 5 mm OZ design provoked a greater flattening, more powerful midperipheral ring and 4^{th}-order corneal and total spherical aberration than the 6 mm OZ design, being statistically significant after 7 days, for corneal aberration, and 15 days, for corneal and total, of wearing the lens (p-value < 0.05). The OZT obtained were 2.8 ± 0.2 mm and 3.1 ± 0.1 mm for 5 mm and 6 mm OZ design, respectively (p-value < 0.05). Regarding PRW, the 5 mm OZ design had a wider ring width in both the nasal and temporal zones (p-value < 0.05). *Conclusions*. A smaller diameter optical zone (5 mm) in orthokeratology lenses produces a smaller treatment area and a larger and more powerful midperipheral ring, increasing the 4^{th}-order spherical aberration that affects only the contrast sensitivity but without differences in visual acuity and subjective vision compared with a larger OZ diameter (6 mm).

1. Introduction

Currently, orthokeratology (OrthoK) has become a clinically reliable and effective method to correct refractive errors using specialty gas permeable contact lenses [1–3]. OrthoK contact lenses are worn overnight and removed in the morning upon awakening, and they provide great quality of vision [3]. A strong advantage with OrthoK is that it is a reversible procedure, so when the use of the lens ceases completely, the cornea recovers to its initial physiological state [4–6].

The tear film under the OrthoK lens reshapes the cornea in closed eye conditions by applying a positive push pressure over the central cornea and a negative pull pressure in the midperiphery [2]. This produces corneal flattening in the central treatment zone to reduce corneal power for myopia correction and corneal steepening, creating a plus power, in the midperiphery. Previous studies have shown changes in corneal thickness with the epithelium thinning in the central zone and thickening in the midperiphery [5, 7, 8].

Orthokeratology was originally prescribed for adults to correct myopia during the day without glasses or contact lens wear [9]. Currently, the majority of OrthoK lenses are being prescribed for myopia control. Several studies have demonstrated the efficacy of OrthoK in slowing down axial length elongation [10–15]. Together with soft contact lenses and pharmacological treatments such as atropine, OrthoK is considered one of the most effective treatment options for slowing myopia progression [15]. The mechanism of action by which OrthoK lenses slow myopia progression is not

completely known. Peripheral defocus, as described in animal models is the most common theory [16–18]. Myopic children are found to have a peripheral hyperopic defocus. OrthoK lenses reshape the midperipheral cornea to steepen, which increases the power, causing a peripheral myopic defocus. This could be a factor in slowing down the axial growth and myopia progression [19–21].

Together with peripheral defocus, higher-order aberrations have been associated with myopia control, mainly 4^{th}-order spherical aberration and coma [22, 23]. Faria-Ribeiro et al. described that higher-order aberrations are associated with larger pupil diameters as well as the effect on myopia control, potentially as a result of a larger retinal area exposed to the peripheral myopic defocus [24]. Many studies have shown that higher-order aberrations increase significantly after OrthoK treatment, even in successful fittings [23, 25].

Thus, newer OrthoK lens designs are trying to increase the peripheral myopic defocus and take into account pupil size dependence in higher-order aberrations. These lenses are being developed with a smaller optical zone (OZ) in attempts to achieve a smaller treatment zone and a steeper, more power midperipheral ring closer to the pupil. There are few studies published that have studied the effect of lens design over the cornea [26–28]. The purpose of this study was to evaluate the topographical effect of changing the optical zone (OZ) diameter in OrthoK in patients with high myopia (−4.00 D to −7.00 D) and to study the effect over visual quality. This will enhance our understanding of the effects of OrthoK lens design over a topography profile.

2. Materials and Methods

A prospective, longitudinal, and randomized pilot study has been conducted. Twelve healthy subjects (18 eyes, 8 women and 4 men) were recruited in the Faculty of Optics and Optometry (Complutense University of Madrid, Spain). The mean age of patients was 25.01 ± 6.91 years (range 18–27 years old) and mean spherical refractive error -4.72 ± 0.36 diopters (D) (range −4.00 D to −7.00 D). Each subject signed an informed consent after the study protocol, and risk and benefits of the treatment were explained. Participants were free to leave the study at any time without any reason. This study obtained ethical approval from the Ethical Committee of the Complutense University of Madrid and followed the tenets of the Declaration of Helsinki [29].

Inclusion criteria were myopia between −4.00 diopters (D) and −7.00 D and with astigmatism less or equal to −1.50 D. Exclusion criteria were history of ocular disease or systemic disease that could affect visual system or pregnancy. Contact lens wearers were asked to stop wearing their habitual contact lens one week before the examination day. All subjects were fit with Paragon CRT™ contact lenses (Paragon Vision Sciences, Gilbert, AZ) in HDS 100 material (paflufocon D, Dk = 100 barrer) according to manufacturer guidelines.

The study was divided into two phases, in which the patient used two different types of OrthoK lenses: a lens with 6 mm OZ diameter and another lens with 5 mm OZ (Table 1). Patients were randomly chosen to start with one of the lens designs and wear the lens consistently for 15 days and 14 nights [30]. This was then followed by 15 days of washout time without any contact lens wear in an attempt to allow the cornea to return to its physiological baseline [31]. Then the patient would resume contact lens wear for 15 days with the other lens design. Investigators made sure to give proper instruction to the patient of handling and care of lenses, including application and removal of OrthoK and contact lens solution care system.

Refraction without cycloplegia, high (HC) and low (LC) contrast uncorrected visual acuity (UCVA), HC and LC best-corrected visual acuity (BCVA), contrast sensitivity, corneal topography, anterior corneal and total wavefront aberration, and Visual Analogue Scale (VAS) questionnaire were performed. All measurements were performed at baseline for pretreatment records (PRE), at 1 day (after the first night of lens wear), at 7 days, and at 15 days for both lens designs, except for total wavefront aberration, contrast sensitivity, and LC BCVA and UCVA. All measurements were taken early in the morning, so that the patient had slept with the lenses for at least 6 hours. A slit lamp examination was performed in all visits to verify the ocular surface integrity.

Corneal topography was taken with the Scheimpflug camera system, Oculus Pentacam (Oculus, Wetzlar, Germany). Parameters obtained with Pentacam included flat keratometry (flat k), steep keratometry (steep k), and corneal radii in X-axis from 4 mm of distance to the apex in both nasal and temporal directions. In addition, optical zone treatment diameter (OZT) and peripheral ring width (PRW) were defined. The OZT was defined as the central zone of corneal flattening from baseline after OrthoK wear. Margins of this zone were marked from comparison map topography data, considering the OZT diameter where the difference between before and after orthokeratology wear was zero. The corneal zone where the corneal radius was steepened during OrthoK lens wear from baseline reading was defined as PRW. PRW margins were considered as the width between OZT margins and where the corneal radius returns (from steepening) the same before and after OrthoK lens wear. PRW was measured in the nasal and temporal zones of X-axis (Figure 1).

Subjective refraction was performed based on the patients' current spectacle prescription, and a fogging method was created for obtaining the final subjective refraction. The astigmatism was adjusted by crossed cylinder technique. The main objective was to find the BCVA with the maximum positive sphere. UCVA and BCVA were measured monocularly in photopic luminance conditions (85 cd/m^2) using the ETDRS test form Chart Display VX24 (Visionix Ltd., Visionix-Luneau Technologies, Chartres, France) with HC (contrast level 100%) and LC (contrast level 10%) at 4 meters. LC BCVA and UCVA were measured at baseline and 15 days after each lens design; HC BCVA and UCVA were measured at all visits. Contrast sensitivity was measured using the Pelli-Robson test at 1 meter, in which spatial frequency corresponds to 1 cycle per degree. VX110 (Visionix-Luneau, France) was used to determine the changes in 4^{th}-order spherical aberration for corneal and total spherical aberrations.

Table 1: Contact lens parameters used during the study.

Parameter	6 mm OZ lens design	5 mm OZ lens design
Manufacturer	Paragon vision sciences (Gilbert, AZ)	Paragon vision sciences (Gilbert, AZ)
Material (USAN)	Paflufocon D	Paflufocon D
Brand	Paragon CRT	Paragon CRT
Back surface geometry	Sigmoid geometry	Sigmoid geometry
Front surface geometry	Mirrored with anterior surface	Mirrored with anterior surface
Overall diameter	10.50	10.50
Optic zone diameter	6.00	5.00
Reverse curve (RZD) width	1.00	1.00
Landing curve (LZA) width	1.00	1.50
Power fitted (D)	+0.50	+0.50
Back optic zone radius (mm)	7.90 to 8.90	7.90 to 8.90

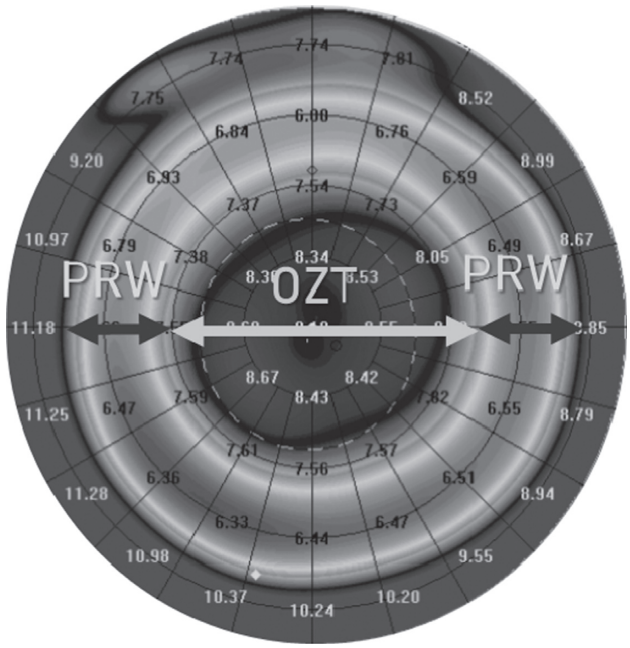


Figure 1: Tangential topography map to show the optical zone treatment (OZT) and peripheral ring width (PRW), both parameters analyzed in this study.

2.1. Statistical Analysis. Statistical analysis was performed using the SPSS Statistics 23 software (IBM, Chicago, Illinois, USA). Sample size calculations were performed with statistical software Granmo 6.0 (Institut Municipal d'Investigació Mèdica, Barcelona, Spain). A statistical power of 80% was considered. Considering the horizontal corneal radius as the main variable, with an accepted two-sided statistical significant threshold of 0.05 and a risk of 0.20, for a standard deviation of 0.06 units to the mean and in order to detect a difference of 0.05 units, at least 12 subjects were needed to find statistically significant differences. Normality of samples was analyzed using the Kolgomorov–Smirnov test. To analyze the differences between the baseline and additional visits and also between both lens designs in the same visit, a Student's t-test for paired samples has been used. Repeated measures ANOVA test was performed to evaluate the trend of the different parameters tested during the study. Results are shown as mean ± standard deviation, and a statistical significance of 95% was established ($p < 0.005$).

3. Results

All patients completed the study without drop outs. No significant differences were found between any baseline measurements for the same subject in the two different lenses (p value > 0.05; Student's t-test for paired samples). Refraction improved from the first day of OrthoK lens wear (p value < 0.05; Student's t-test for paired samples), being -2.51 ± 0.35 D and -2.87 ± 0.97 D for 1 day of wear and -0.31 ± 0.80 D and -0.35 ± 0.51 D at 15 days of wearing for 5 mm OZ and 6 mm OZ designs, respectively. No differences in refraction were found between designs (p value > 0.05; Student's t-test for paired samples).

Table 2 summarizes the mean values and standard deviations of visual acuity and contrast sensitivity obtained during the baseline and follow-up visits. HC UCVA was statistically lower than HC BCVA after one day of orthokeratology lenses for both OZ designs (p value < 0.05; Student's t-test for paired samples). However, after seven days of wearing, both designs showed HC UCVA improvement, reaching the BCVA at the baseline (p value > 0.05; Student's t-test for paired samples). In addition, no differences were found between designs for any visit studied (p value > 0.05; Student's t-test for paired samples). Regarding LC visual acuity, 6 mm OZ lenses showed a decrease in LC UCVA after 15 days of wear compared with LC BCVA at the baseline (p value = 0.004; Student's t-test for paired samples). Meanwhile, with the 5 mm OZ design, LC UCVA was slightly worse than LC BCVA but not statistically significant (p value > 0.05; Student's t-test for paired samples). As HC visual acuity, no differences were found for LC visual acuity between designs for any visit studied (p-value > 0.05; Student's t-test for paired samples).

The contrast sensitivity (CS) was also evaluated. No differences were found between orthokeratology lens designs (p value > 0.05; Student's t-test for paired samples). However, during 5 mm OZ wearing, CS statistically decreased (p value = 0.003; Student's t-test for paired samples). While the 6 mm OZ wearing provoked a slight increase in CS, this was not statistically significant (p value = 0.195; Student's t-test for paired samples).

Table 2: High- and low- contrast visual acuity during orthokeratology wear at different visits.

Parameter (mean ± SD)	HC VA (logMAR)			LC VA (logMAR)			CS (logMAR)		
Optical zone diameter (mm)	5 mm	6 mm	p value	5 mm	6 mm	p value	5 mm	6 mm	p value
PRE (BCVA)	−0.03 ± 0.12	-0.01 ± 0.11	0.822	0.18 ± 0.09	0.17 ± 0.11	0.734	1.84 ± 0.16	1.59 ± 0.66	0.164
1 day (UCVA)	0.52 ± 0.36	0.38 ± 0.30	0.138	—	—		—	—	—
7 days (UCVA)	0.02 ± 0.30	−0.08 ± 0.16	0.176	—	—		—	—	—
15 days (UCVA)	−0.02 ± 0.12	−0.04 ± 0.09	0.730	0.23 ± 0.33	0.38 ± 0.16	0.252	1.47 ± 0.59	1.67 ± 0.05	0.210

D: diopters; mm: millimeters; SD: standard deviation; VA: visual acuity; CVA: corrected visual acuity; UCVA: uncorrected visual acuity; HC: high contrast; LC: low contrast; CS: contrast sensitivity.

Regarding corneal topography, Figure 2 shows central corneal flattening after orthokeratology lens wear from the first day, being statistically significant for both vertical and horizontal radii in all visit evaluated (p value < 0.05; Student's t-test for paired samples). The 5 mm OZ design had a statistically significant greater flattening than 6 mm OZ design after 7 and 15 days of wearing the lens (p value < 0.05; Student's t-test for paired samples). The horizontal and vertical corneal radius flattening differences between lens designs after 15 days of wearing were 0.13 ± 0.02 mm and 0.14 ± 0.06 mm, respectively.

The keratometric or topography profile of the cornea for each OZ lens design before 15 days of lens wear is displayed in Figure 3. These profiles were created by comparing baseline keratometry and the keratometry measurements after 15 days of wear in OrthoK. The 5 mm OZ design produced greater central flattening and greater midperipheral steepening than 6 mm OZ design for all follow-up visits (p value < 0.05; Student's t-test for paired samples). Table 3 shows the changes in corneal radii at different points to the apex in X-axis. The treatment size of the 5 mm OZ lens design was 2.8 ± 0.2 mm and 3.1 ± 0.1 mm with 6 mm OZ lens design, with a statistically difference (p value = 0.024; Student's t-test for paired samples) (Table 4). Regarding PRW, a statistical significance difference was found for the nasal and temporal zone between both lens design, being wider for 5 mm OZ design (p value = 0.037 and p value = 0.049 for nasal and temporal, respectively; Student's t-test for paired samples). These differences provoke a very different keratometric profile in the X-axis, with the changes between central cornea and peripheral ring more abrupt. This demonstrates that for 1.00 D of anterior corneal power difference (between the center and the periphery), the 5 mm OZ design measured 1.3 mm to the center. The 6 mm OZ design is a wider measurement of 2.1 mm. Likewise, to reach a power difference of 1.50 D from the center and the periphery, the 5 mm OZ lens design was measured at 2.1 mm and 2.4 mm for the 6 mm OZ designs.

Corneal and total spherical aberration with a 5 mm pupil diameter was also evaluated. Both 4th-order corneal and total spherical aberrations (Z12) had a statistical significant difference for all follow-up visits compared with baseline for both OZ lens designs ($p < 0.05$; Student's t-test for paired samples), trending towards greater positive corneal spherical aberration. Comparing both designs, no statistical differences were found at baseline and wearing OrthoK after 1 day; however, the 5 mm OZ design showed greater positive spherical aberration than the 6 mm OZ design after 7 and 15 days of wearing the lens, representing a statistical significant difference for both corneal and total spherical aberrations ($p < 0.05$; Student's t-test for paired samples). See Table 5.

Regarding VAs, no significant differences were found between either OrthoK OZ designs for subjective comfort and vision ($p > 0.05$; Student's t-test for paired samples). However, less corneal staining was observed in 37.5% of eyes with 6 mm OZ diameter compared to 62.5% with 5 mm OZ diameter (Figure 4).

4. Discussion

The current study had the aim to analyze the effect of different OZ diameters of OrthoK lenses over the topography profile in high myopia patients. The 5 mm OZ lens design is able to generate a greater midperipheral curvature and central flattening than 6 mm OZ design. This profile difference means that smaller OZ produces a narrower treatment area and a wider and steeper peripheral ring, closing the steepening ring to the pupil center.

Currently, the scientific literature regarding the effect of lens design, and in particular the optical zone diameter, in OrthoK lenses is very weak. Few studies have been published in this interesting research field [26–28]. Kang et al. described that decreasing the OZ of OrthoK lenses produces minimal effects in corneal molding and in peripheral refraction in low myopia (−1.00 D to −4.00 D) [26], opposite than what was discovered and described in this manuscript. The main difference between these studies could be the initial amount of myopia treated and also the lens design. Kang et al. recruited patients from −1.00 D to −4.00 D, while in the current study, the myopia range was from −4.00 D to −7.00 D.

Changes in the topographic profile, including a wider, steeper midperipheral ring, and closer to the pupil center, has been hypothesized as an important factor in improving the efficacy of myopia control with OrthoK lenses [24, 27, 32]. In a study published in 2016, Kang et al. suggested that inducing greater degrees of myopic defocus on the peripheral retina, more than what is habitually experienced in a typical OrthoK lens, may be required for effective myopia control [33]. On the other hand, another study concluded that different contact lens designs for OrthoK do not provoke significant differences in peripheral refraction [28]. The ring of peripheral curvature closer to the pupil center with 5 mm OZ design and with greater midperipheral corneal power could improve the efficacy in myopia control, although there are no studies that corroborate this hypothesis. A limitation of the present study is

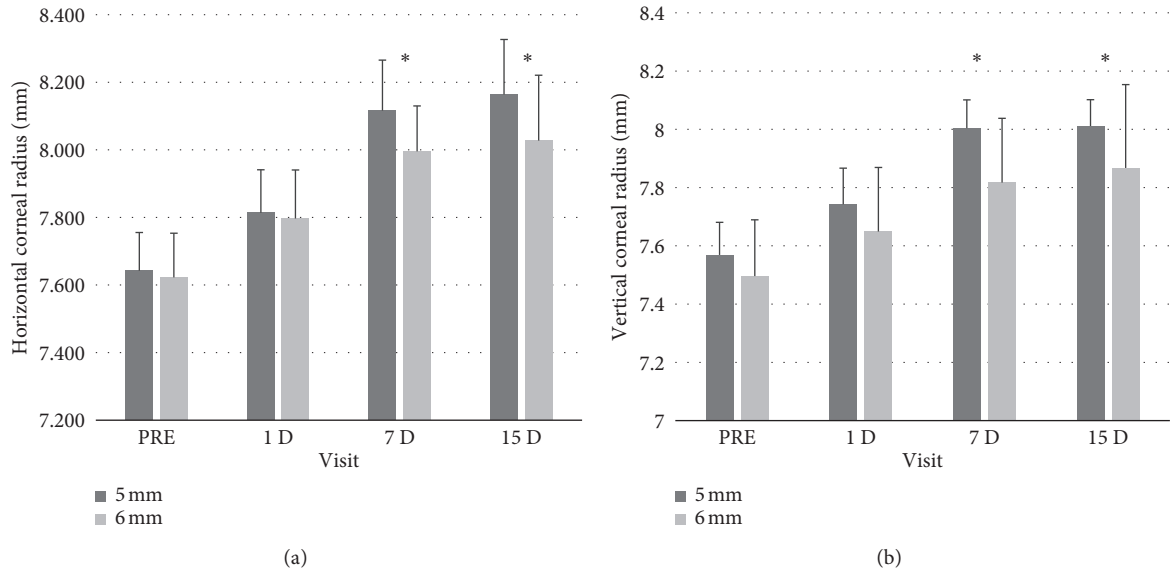


Figure 2: Horizontal and vertical corneal radius in the different visits with 5 mm and 6 mm optic zone lenses ∗ 5 mm OZ vs. 6 mm OZ (p value < 0.05; Student's t-test for the related samples).

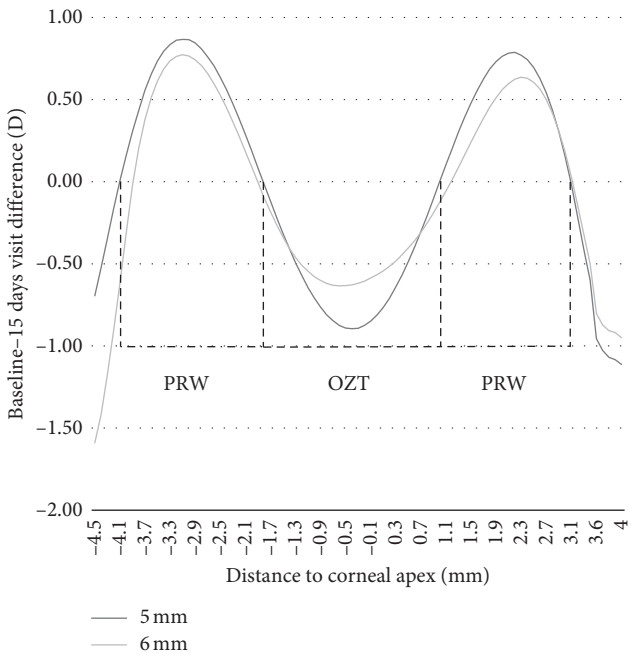


Figure 3: Mean corneal radius differences along the horizontal axis between baseline (before orthokeratology wearing) and day 15 for 5 mm and 6 mm OZ lens designs (BASELINE-15 d). Standard deviation has been removed for a better profile comprehension. Negative values mean flattening and positive values mean steepening. Complete data are show in Table 4. OZT: optical zone treatment; PRW: peripheral ring power.

that it was not possible to measure peripheral refraction in these patients recruited, and therefore, it is not possible to assert that the topographic profile changes with orthokeratology have impact in myopia progression.

Visual quality is another factor to consider when patients are fit in OrthoK lenses. There are a lot of studies published describing a decrease in visual quality during OrthoK treatment [25, 34–37]. OrthoK changes refraction by flattening the central cornea and subsequently steepening the midperipheral cornea [2]. It would be expected that 5 mm OZ design shows faster refraction correction, but the results of this study do not show differences between both OZ designs. In addition, for HC and LC visual acuity, findings were in the same way, no differences between lens designs. Nevertheless, contrast sensitivity was only decreased with 5 mm OZ orthokeratology design wearing. Hiraoka et al. described a significant decrease of contrast sensitivity after wearing OrthoK lenses, but there is no scientific literature published regarding the effect of OZ diameter over the contrast sensitivity [38, 39]. Liu et al. found that contrast sensitivity decreases after orthokeratology treatment, being alleviated by a larger treatment zone diameter and a smaller lens decentration [34]. In addition, Jung et al. described that tinted contact lenses significantly increased ocular aberrations and decreased contrast sensitivity in function of pigment-free optical zone diameter decreasing [40], taking into account that the differences in 4th-order spherical aberration found between both designs studied could be the most probable reason to observe lower contrast sensitivity with smaller OZ diameter in OrthoK.

Given the nature of OrthoK treatment which produces a molding on the corneal surface, it is expected that changes occur with corneal aberrations, and consequently total aberrations [41, 42]. Higher-order aberrations are directly influenced by pupil diameter [24], affecting the mesopic and scotopic visual quality. The results obtained in this study, with both OZ designs, agree with previous studies [24, 25, 37, 43, 44]. As would be expected, the aberrations are greater with the 5 mm OZ design than with the 6 mm OZ design, due to the differences in the topography profile achieved with each lens design. This fact could explain the lower contrast sensitivity with the smaller 5 mm OZ design.

Table 3: Mean corneal radius differences along the horizontal axis between baseline (before orthokeratology wear) and day 15 for 5 mm and 6 mm OZ lens designs (baseline – 15 d).

Lens design	Parameter (mean ± SD)	Corneal radius (baseline – PRE)								
OZ 5 mm lens	Distance to apex (mm)	**−4.00**	**−3.00**	**−2.00**	**−1.00**	**0.00**	**1.00**	**2.00**	**3.00**	**4.00**
	1 day	−0.04 ± 0.20	0.101 ± 0.19	0.24 ± 0.12	−0.16 ± 0.10	−0.38 ± 0.13	0.07 ± 0.08	0.28 ± 0.09	−0.13 ± 0.27	−0.11 ± 0.40
	7 days	0.02 ± 0.38	0.69 ± 0.29	0.30 ± 0.16	−0.66 ± 0.20	−0.84 ± 0.07	0.11 ± 0.15	0.69 ± 0.19	−0.09 ± 0.39	−0.73 ± 0.82
	15 days	0.15 ± 0.44	0.86 ± 0.36	0.19 ± 0.22	−0.70 ± 0.18	−0.81 ± 0.10	0.00 ± 0.20	0.76 ± 0.27	0.15 ± 0.41	−1.11 ± 1.11
OZ 6 mm lens	Distance to apex (mm)	**−4.00**	**−3.00**	**−2.00**	**−1.00**	**0.00**	**1.00**	**2.00**	**3.00**	**4.00**
	1 day	−0.22 ± 0.36	0.30 ± 0.22	0.13 ± 0.12	−0.18 ± 0.10	−0.28 ± 0.15	−0.04 ± 0.17	0.30 ± 0.12	0.01 ± 0.31	−0.22 ± 0.37
	7 days	−0.17 ± 0.29	0.65 ± 0.43	0.16 ± 0.21	−0.48 ± 0.17	−0.57 ± 0.19	−0.07 ± 0.29	0.53 ± 0.22	0.08 ± 0.59	−0.81 ± 1.14
	15 days	−0.31 ± 1.51	0.77 ± 0.48	0.09 ± 0.26	−0.57 ± 0.31	−0.56 ± 0.12	−0.12 ± 0.28	0.56 ± 0.28	0.18 ± 0.67	−0.95 ± 1.10

Negative values mean flattening and positive values mean steepening. OZ: optical zone; SD: standard deviation.

Table 4: Average widths (mm) of optical zone and peripheral rings obtained after 15 days of orthokeratology lenses wear.

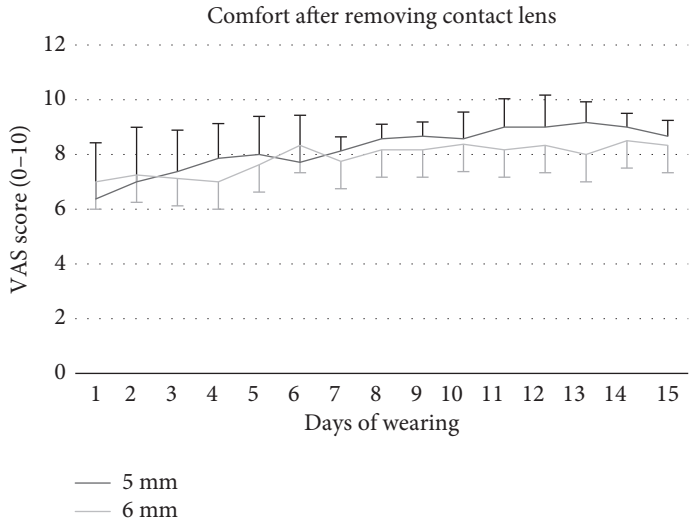
	5 mm OZ lens	6 mm OZ lens	p value
Nasal PRW	2.3 ± 0.2	1.9 ± 0.1	0.037*
OZT	2.8 ± 0.2	3.1 ± 0.1	0.024*
Temporal PRW	2.4 ± 0.1	2.2 ± 0.2	0.047*

Values are expressed as mean ± SD. SD: standard deviation; OZT: optical zone treatment; PRW: peripheral ring width. * p value < 0.05; (Student's t-test for paired samples; 5 mm OZ vs. 6 mm OZ).

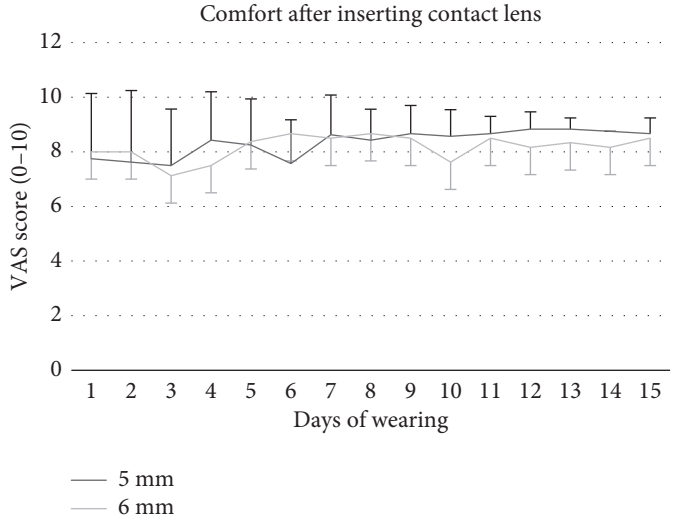
Table 5: Corneal and total spherical aberration measured with Visionix VX110 at 5 mm pupil diameter.

	Corneal Z12 (μm)			Total Z12 (μm)		
Visit	5 mm OZ lens	6 mm OZ lens	p value	5 mm OZ lens	6 mm OZ lens	p value
PRE	0.144 ± 0.030	0.132 ± 0.029	0.854	0.041 ± 0.054	0.011 ± 0.029	0.456
1 day	0.403 ± 0.083	0.331 ± 0.089	0.526	—	—	—
7 days	0.644 ± 0.101	0.477 ± 0.153	0.027*	—	—	—
15 days	0.603 ± 0.116	0.476 ± 0.124	0.039*	0.574 ± 0.496	0.451 ± 0.199	0.043*

Values are expressed as mean ± SD. SD: standard deviation; OZ: optical zone; Z12: 4th spherical aberration. * $p < 0.05$ comparison between lenses (Student's t-test for paired samples).

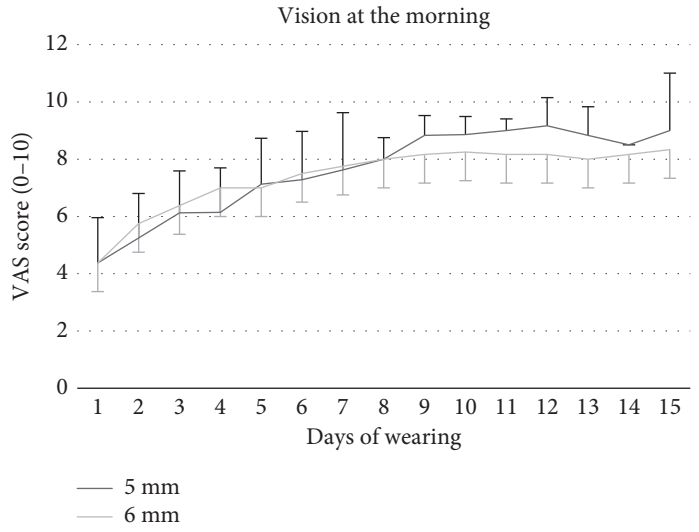


(a)

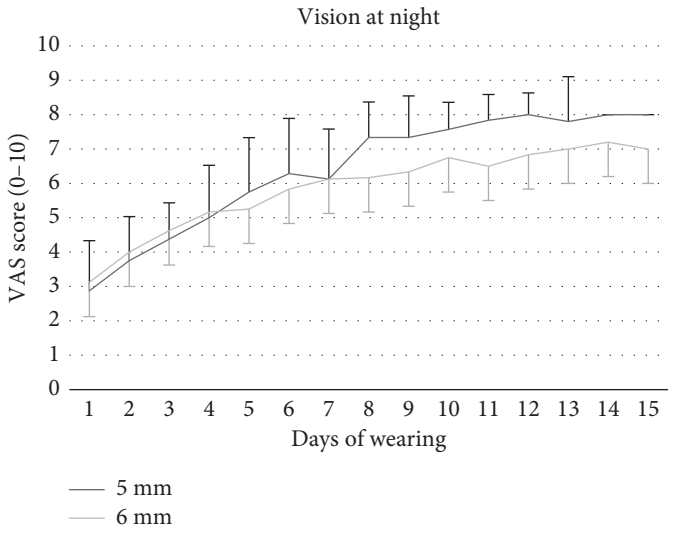


(b)

Figure 4: Continued.



(c)



(d)

Figure 4: Subjective comfort and visual ratings obtained in the Visual Analogue Scale (VAS) questionnaire with a 5 mm and 6 mm OZ lens design.

However, this loss of visual quality was not extrapolated to change subjective visual satisfaction. Both contact lens designs showed similar scores, even with a slight positive trend in 5 mm OZ design for vision at night compared with the 6 mm OZ lens. This means that an aberrometric alteration occurs with this change in OZ design, even in successful fitting.

In conclusion, a smaller diameter OZ in OrthoK lenses produces a smaller treatment area and a larger and more powerful midperipheral ring, increasing the 4^{th}-order spherical aberration that affects only the contrast sensitivity, but without differences in terms of visual acuity and subjective vision, compared to a lens design with a larger OZ diameter. More studies are needed to understand if these outcomes only represent corneal modifications or if a smaller treatment zone and more powerful midperipheral ring, closer to the pupil center, play an important role in increasing the efficacy of myopia control in an OrthoK lens.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] C. McAlinden and M. Lipson, "Orthokeratology and contact lens quality of life questionnaire (OCL-QoL)," *Eye and Contact Lens: Science and Clinical Practice*, vol. 44, no. 5, pp. 279–285, 2017.

[2] H. A. Swarbrick, "Orthokeratology review and update," *Clinical and Experimental Optometry*, vol. 89, no. 3, pp. 124–143, 2006.

[3] H. A. Swarbrick, "Orthokeratology (corneal refractive therapy)," *Eye and Contact Lens: Science and Clinical Practice*, vol. 30, no. 4, pp. 181–185, 2004.

[4] A. González-Mesa, C. Villa-Collar, A. Lorente-Velázquez, and A. Nieto-Bona, "Anterior segment changes produced in response to long-term overnight orthokeratology," *Current Eye Research*, vol. 38, no. 8, pp. 862–870, 2013.

[5] A. Nieto-Bona, A. González-Mesa, M. P. Nieto-Bona, C. Villa-Collar, and A. Lorente-Velázquez, "Long-term changes in corneal morphology induced by overnight orthokeratology," *Current Eye Research*, vol. 36, no. 10, pp. 895–904, 2011.

[6] A. Nieto-Bona, A. González-Mesa, M. P. Nieto-Bona, C. Villa-Collar, and A. Lorente-Velázquez, "Short-term effects of overnight orthokeratology on corneal cell morphology and corneal thickness," *Cornea*, vol. 30, no. 6, pp. 646–654, 2011.

[7] Y. Qian, F. Xue, J. Huang, X. Qu, X. Zhou, and D. V. Lanen-Wanek, "Pachymetry map of corneal epithelium in children wearing orthokeratology contact lenses," *Current Eye Research*, vol. 39, no. 3, pp. 263–270, 2013.

[8] D. Z. Reinstein, M. Gobbe, T. J. Archer, D. Couch, and B. Bloom, "Epithelial, stromal, and corneal pachymetry changes during orthokeratology," *Optometry and Vision Science*, vol. 86, no. 8, pp. E1006–E1014, 2009.

[9] D. R. Wilson and A. H. Keeney, "Corrective measures for myopia," *Survey of Ophthalmology*, vol. 34, no. 4, pp. 294–304, 1990.

[10] P. Kang, "Optical and pharmacological strategies of myopia control," *Clinical and Experimental Optometry*, vol. 101, no. 3, pp. 321–332, 2018.

[11] Y. C. Lee, J. H. Wang, and C. J. Chiu, "Effect of Orthokeratology on myopia progression: twelve-year results of a retrospective cohort study," *BMC Ophthalmology*, vol. 17, no. 1, p. 243, 2017.

[12] Y. Cui, L. Li, Q. Wu et al., "Myopia correction in children: a meta-analysis," *Clinical and Investigative Medicine*, vol. 40, no. 3, pp. E117–E126, 2017.

[13] P. Cho and S.-W. Cheung, "Protective role of orthokeratology in reducing risk of rapid axial elongation: a reanalysis of data from the ROMIO and TO-SEE studies," *Investigative Opthalmology and Visual Science*, vol. 58, no. 3, pp. 1411–1416, 2017.

[14] S. W. Leo and O. Scientific Bureau, "Current approaches to myopia control," *Current Opinion in Ophthalmology*, vol. 28, no. 3, pp. 267–275, 2017.

[15] J. Huang, D. Wen, Q. Wang et al., "Efficacy comparison of 16 interventions for myopia control in children," *Ophthalmology*, vol. 123, no. 4, pp. 697–708, 2016.

[16] J. Woods, S. E. Guthrie, N. Keir et al., "Inhibition of defocus-induced myopia in chickens," *Investigative Opthalmology and Visual Science*, vol. 54, no. 4, pp. 2662–2668, 2013.

[17] Y. Liu and C. Wildsoet, "The effective add inherent in 2-zone negative lenses inhibits eye growth in myopic young chicks," *Investigative Opthalmology and Visual Science*, vol. 53, no. 8, pp. 5085–5093, 2012.

[18] Y. Liu and C. Wildsoet, "The effect of two-zone concentric bifocal spectacle lenses on refractive error development and eye growth in young chicks," *Investigative Opthalmology and Visual Science*, vol. 52, no. 2, pp. 1078–1086, 2011.

[19] J. M. González-Méijome, G. Carracedo, D. Lopes-Ferreira, M. A. Faria-Ribeiro, S. C. Peixoto-de-Matos, and A. Queirós, "Stabilization in early adult-onset myopia with corneal refractive therapy," *Contact Lens and Anterior Eye*, vol. 39, no. 1, pp. 72–77, 2016.

[20] J. M. González-Méijome, M. A. Faria-Ribeiro, D. P. Lopes-Ferreira, P. Fernandes, G. Carracedo, and A. Queiros, "Changes in peripheral refractive profile after orthokeratology for different degrees of myopia," *Current Eye Research*, vol. 41, no. 2, pp. 199–207, 2015.

[21] A. Queiros, J. M. Gonzalez-Meijome, J. Jorge, C. Villa-Collar, and A. R. Gutierrez, "Peripheral refraction in myopic patients after orthokeratology," *Optometry and Vision Science*, vol. 87, no. 5, pp. 323–329, 2010.

[22] P. Gifford and K. L. Gifford, "The future of myopia control contact lenses," *Optometry and Vision Science*, vol. 93, no. 4, pp. 336–343, 2016.

[23] T. Hiraoka, T. Mihashi, C. Okamoto, F. Okamoto, Y. Hirohara, and T. Oshika, "Influence of induced decentered orthokeratology lens on ocular higher-order wavefront aberrations and contrast sensitivity function," *Journal of Cataract and Refractive Surgery*, vol. 35, no. 11, pp. 1918–1926, 2009.

[24] M. Faria-Ribeiro, R. Navarro, and J. M. González-Méijome, "Effect of pupil size on wavefront refraction during orthokeratology," *Optometry and Vision Science*, vol. 93, no. 11, pp. 1399–1408, 2016.

[25] P. Gifford, M. Li, H. Lu, J. Miu, M. Panjaya, and H. A. Swarbrick, "Corneal versus ocular aberrations after overnight orthokeratology," *Optometry and Vision Science*, vol. 90, no. 5, pp. 439–447, 2013.

[26] P. Kang, P. Gifford, and H. Swarbrick, "Can manipulation of orthokeratology lens parameters modify peripheral refraction?," *Optometry and Vision Science*, vol. 90, no. 11, pp. 1237–1248, 2013.

[27] R. Marcotte-Collard, P. Simard, and L. Michaud, "Analysis of two orthokeratology lens designs and comparison of their optical effects on the cornea," *Eye Contact Lens*, vol. 44, no. 5, pp. 322–329, 2018.

[28] P. Kang and H. Swarbrick, "The influence of different OK lens designs on peripheral refraction," *Optometry and Vision Science*, vol. 93, no. 9, pp. 1112–1119, 2016.

[29] World Medical Association, "World medical association declaration of Helsinki: ethical principles for medical research involving human subjects," *JAMA*, vol. 310, no. 20, pp. 2191–2194, 2013.

[30] P. S. Soni, T. T. Nguyen, and J. A. Bonanno, "Overnight orthokeratology," *Eye and Contact Lens: Science and Clinical Practice*, vol. 29, no. 3, pp. 137–145, 2003.

[31] P. S. Soni, T. T. Nguyen, and J. A. Bonanno, "Overnight orthokeratology," *Eye and Contact Lens: Science and Clinical Practice*, vol. 30, no. 4, pp. 254–262, 2004.

[32] J. Pauné, S. Thivent, J. Armengol, L. Quevedo, M. Faria-Ribeiro, and J. M. González-Méijome, "Changes in peripheral refraction, higher-order aberrations, and accommodative lag with a radial refractive gradient contact lens in young myopes," *Eye and Contact Lens: Science and Clinical Practice*, vol. 42, no. 6, pp. 380–387, 2016.

[33] P. Kang and H. Swarbrick, "New perspective on myopia control with orthokeratology," *Optometry and Vision Science*, vol. 93, no. 5, pp. 497–503, 2016.

[34] G. Liu, Z. Chen, F. Xue et al., "Effects of myopic orthokeratology on visual performance and optical quality," *Eye Contact Lens*, vol. 44, no. 5, pp. 316–321, 2017.

[35] T. Hiraoka, F. Okamoto, Y. Kaji, and T. Oshika, "Optical quality of the cornea after overnight orthokeratology," *Cornea*, vol. 25, no. 10, pp. S59–S63, 2006.

[36] J. Santodomingo-Rubido, C. Villa-Collar, B. Gilmartin, R. Gutiérrez-Ortega, and A. Suzaki, "Short- and long-term changes in corneal aberrations and axial length induced by

orthokeratology in children are not correlated," *Eye and Contact Lens: Science and Clinical Practice*, vol. 43, no. 6, pp. 358–363, 2017.

[37] I. Stillitano, P. Schor, C. Lipener, and A. L. Hofling-Lima, "Long-term follow-up of orthokeratology corneal reshaping using wavefront aberrometry and contrast sensitivity," *Eye and Contact Lens: Science and Clinical Practice*, vol. 34, no. 3, pp. 140–145, 2008.

[38] T. Hiraoka, C. Okamoto, Y. Ishii, F. Okamoto, and T. Oshika, "Recovery of corneal irregular astigmatism, ocular higher-order aberrations, and contrast sensitivity after discontinuation of overnight orthokeratology," *British Journal of Ophthalmology*, vol. 93, no. 2, pp. 203–208, 2008.

[39] T. Hiraoka, C. Okamoto, Y. Ishii, T. Kakita, and T. Oshika, "Contrast sensitivity function and ocular higher-order aberrations following overnight orthokeratology," *Investigative Opthalmology and Visual Science*, vol. 48, no. 2, pp. 550–556, 2007.

[40] J. W. Jung, S. M. Kim, S. H. Han, E. K. Kim, K. Y. Seo, and T.-i. Kim, "Effect of the pigment-free optical zone diameter of decorative tinted soft contact lenses on visual function," *British Journal of Ophthalmology*, vol. 100, no. 5, pp. 633–637, 2015.

[41] T. Hiraoka, Y. Matsumoto, F. Okamoto et al., "Corneal higher-order aberrations induced by overnight orthokeratology," *American Journal of Ophthalmology*, vol. 139, no. 3, pp. 429–436, 2005.

[42] R. G. Anera and C. Villa, "Visual differences after corneal refractive therapy and LASIK," *Journal of Refractive Surgery*, vol. 26, no. 9, pp. 622-623, 2010.

[43] J. Santodomingo-Rubido, C. Villa-Collar, B. Gilmartin, R. Gutiérrez-Ortega, and A. Suzaki, "The effects of entrance pupil centration and coma aberrations on myopic progression following orthokeratology," *Clinical and Experimental Optometry*, vol. 98, no. 6, pp. 534–540, 2015.

[44] K. L. Johnson, L. G. Carney, J. A. Mountford, M. J. Collins, S. Cluff, and P. K. Collins, "Visual performance after overnight orthokeratology," *Contact Lens and Anterior Eye*, vol. 30, no. 1, pp. 29–36, 2007.

Hindawi
Journal of Ophthalmology
Volume 2018, Article ID 7106028, 6 pages
https://doi.org/10.1155/2018/7106028

Clinical Study

Increased Corneal Toricity after Long-Term Orthokeratology Lens Wear

Zhi Chen,[1,2,3] Jiaqi Zhou,[1,2,3] Feng Xue,[1,2,3] Xingtao Zhou,[1,2,3] and Xiaomei Qu[1,2,3]

[1]*Department of Ophthalmology and Vision Science, Eye and ENT Hospital, Fudan University, Shanghai, China*
[2]*NHC Key Laboratory of Myopia, Fudan University, Shanghai, China*
[3]*Laboratory of Myopia, Chinese Academy of Medical Sciences, Shanghai, China*

Correspondence should be addressed to Xiaomei Qu; quxiaomei2002@126.com

Received 18 May 2018; Revised 12 August 2018; Accepted 19 September 2018; Published 23 October 2018

Academic Editor: Jesús Pintor

Purpose. To investigate the change in corneal toricity and associated refractive astigmatism after discontinuation of long-term orthokeratology (ortho-k) lens wear. *Methods*. This study investigated 136 subjects aged between 6 and 14 (9.1 ± 1.5) years old at the commencement of ortho-k treatment, who had been undergoing overnight ortho-k treatment for 24 to 72 (37.4 ± 11.9) months. Corneal refractive power and manifest refraction were measured and compared before ortho-k and 1 month after discontinuation of ortho-k lens wear. Changes in corneal curvature were analyzed. Corneal curvature data from a historical longitudinal study were used as control. *Results*. Compared to pre-ortho-k values, the corneal curvature became significantly flatter in the flatter meridian (−0.22 ± 0.27 D, $P < 0.001$) and steeper in the steeper meridian (0.06 ± 0.34 D, $P = 0.032$) after cessation of ortho-k lens wear, resulting in a significant increase in corneal toricity (0.28 ± 0.43 D, $P < 0.001$), which is associated with an increase in refractive astigmatism (0.57 ± 0.57 D, $r = 0.465$, $P < 0.001$). The amount of residual corneal flattening in the flatter meridian is significantly affected by the length of ortho-k treatment ($t = -2.965$, $P = 0.004$) and the baseline age of subject ($t = -2.841$, $P = 0.005$), but not by the baseline spherical or cylindrical refractive error (both $P > 0.05$). In the historical control group, there is no significant change in the corneal curvature over two years in children wearing spectacle lenses (both meridians, $P > 0.05$). Change of corneal toricity was more significant in the ortho-k group than in the spectacle control group ($P = 0.001$). *Conclusions*. Long-term ortho-k lens wear increases corneal toricity after discontinuation of the treatment, which is associated with an increase in refractive astigmatism. A more pronounced change in corneal toricity was found in subjects who were younger to start ortho-k and have been in a longer period of treatment. This trial is registered with http://www.chictr.org.cn (ChiCTR-TNRC-11001210).

1. Introduction

Modern orthokeratology (ortho-k) is a nonsurgical procedure designed to temporarily reduce refractive error and improve uncorrected vision by the application of a reverse-geometry gas-permeable rigid contact lens [1, 2]. Ortho-k for myopic correction alters the corneal curvature that makes the central cornea flatter and midperipheral cornea steeper [3]; the mechanism underlying the corneal curvature changes has been shown to be mainly epithelium in origin [4], and these changes are believed to be reversible should patients discontinue ortho-k lens wear for a sufficient length of time [5]. However, little is known about the residual corneal curvature change after long-term ortho-k lens wear.

Barr et al. [6] were the first to investigate the recovery process following overnight reverse-geometry ortho-k lens wear and reported that 72 hours of discontinuation was insufficient for the cornea to recover. Later, Soni et al. [5] conducted a study in which the subjects underwent overnight ortho-k treatment for one month and stopped lens wear for two weeks. After the 2-week washout period, corneal curvature and refractive error largely returned to baseline. However, the treatment period is too short to draw a safe conclusion that the corneal reshaping effect can be fully eliminated after discontinuation of ortho-k lens wear. Kobayashi et al. [7] therefore carried out a 60-week clinical observation, with the first 52 weeks being the ortho-k treatment period and the last 8 weeks being the washout

period. Their data showed a mild but insignificant hyperopic shift in refractive error after 8 weeks of discontinuation of ortho-k lens wear. However, they did not report the corneal curvature data.

Santodomingo-Rubido et al. [8] followed the subjects undergoing ortho-k therapy for 24 months and stopped lens wear in them for one week. They reported that the effects of long-term ortho-k on corneal curvature and refraction are still present after 1-week discontinuation of lens wear. It seems necessary to stop lens wear for a longer period to further testify the reversibility of ortho-k treatment. Credit for the understanding of this issue must be shared by Wu, Stapleton, and Swarbrick, who treated children subjects with ortho-k for an average of 50 months and discontinued lens wear for an average of 17 days [9]. Interestingly, they found a significant residual corneal flattening in the flatter meridian after the discontinuation period, which opens the possibility that long-term ortho-k lens wear has some minor permanent effect on corneal curvature. In agreement with their findings, in our clinical practice, we observed corneal flattening in the flatter meridian and a resultant increase in corneal toricity in some of our patients after discontinuation of long-term ortho-k lens wear. However, without a control group, the question remains open as whether these changes are specific to ortho-k treatment or physiological (i.e., aging effect in children free from ortho-k treatment).

The aim of this study was to investigate the change in corneal toricity and associated refractive astigmatism after discontinuation of long-term ortho-k lens wear and to compare it with children wearing spectacles from a historical control group.

2. Methods

2.1. Ortho-k Subjects. This retrospective study adhered to the tenets of the Declaration of Helsinki. In this study, 136 Chinese subjects who visited the Fudan University Eye and ENT Hospital (Shanghai, China) between August 2017 and January 2018 were consecutively included. The subjects were aged between 6 and 14 (9.1 ± 1.5) years old at the commencement of ortho-k treatment. They have been undergoing ortho-k therapy for a length of 24 to 72 months (37.4 ± 11.9 months) at the time of enrollment and were required to cease lens wear for various reasons, e.g., loss of lens, prescription updates for myopia progression, or routine checkup before reorder. The discontinuation period was 1 month in all cases. Exclusion criteria for this analysis were (1) pre-ortho-k spherical refractive error greater than −5.00 DS (based on noncycloplegic manifest refraction) and (2) limbus-to-limbus corneal astigmatism in the need of toric designed ortho-k lenses as a treatment (a toric designed lens is supposed to yield different tensions on the steeper meridian than a spherical lens does and might confound the corneal curvature results). Ortho-k was performed in both eyes of the subjects but only data from the right eyes were analyzed.

2.2. Ortho-k Lenses. The ortho-k contact lenses worn by all the subjects were spherical four-zone reverse geometry gas-permeable rigid contact lenses (Emerald Series, Euclid, USA) composed of oprifocon A (Boston Equalens II). The lens has a back optical zone diameter (BOZD) of 6.2 mm, a reverse curve of 0.5 mm width, an alignment curve of 1.2 mm width, and a peripheral curve of 0.5 mm width. The total diameter of a typical trial lens is 10.6 mm, and the central thickness is 0.22 mm. Final lenses were prescribed with a total diameter (TD) tailored to the horizontal visible iris diameter (HVID) using the following equation (the maximum TD that can be ordered was 11.4):

$$\mathrm{TD} = \mathrm{HVID} - 1.0 \pm 0.1\ \mathrm{mm}. \quad (1)$$

Over-refraction was performed before the final lenses were ordered. A Jessen factor of 0.75 D was used in all cases. Should significant lens decentration (greater than 1.0 mm) occur or the unaided visual acuity drop below 20/25 during follow-up visits, new lenses would be ordered until a good lens centration was regained and visual acuity restored to over 20/25; otherwise, the lenses were replaced every 12 to 18 months on a regular basis.

2.3. Corneal Topography. Corneal topography was measured with the Placido ring-based Medmont topographer (E300, Medmont, Australia), prior to ortho-k treatment and at every follow-up visit, including the end of the discontinuation period. At least two measurements were taken with difference in K readings not greater than 0.05 D along either meridian. Only those topography maps with an optimal quality (no significant rhinal shade or tear film breakup) were included in the final analysis. The corneal curvature as expressed by simulated K in diopters was recorded before ortho-k treatment and after discontinuation of lens wear.

2.4. Control Group. The control data were from 123 spectacle-wearing children who were enrolled in our earlier studies (data unpublished). They were aged between 6 and 14 (9.4 ± 1.8) years old at baseline and completed the 2-year follow-up study. Corneal topography using Medmont topographer was performed both before treatment and at the completion of follow-up visits. Criteria for the selection of data were identical to the ortho-k group.

2.5. Data Analysis. Refractive sphere and cylinder, corneal curvatures along both meridians, and corneal toricity were compared before ortho-k and after discontinuation of ortho-k lens wear using the paired samples t-test. The effects of pre-ortho-k refractive error, age, and duration of ortho-k treatment on the change in corneal curvature were analyzed using stepwise multiple linear regression analysis. The relationship between the change of corneal toricity and refractive cylinder was analyzed using the Pearson correlation test. Refractive error and corneal curvatures of the subjects were compared between the ortho-k group and the spectacle control group prior to and after treatment using independent samples t-test. A $P < 0.05$ was considered to be statistically significant.

3. Results

Spherical and cylindrical refractive error was −2.53 ± 1.07 DS (range, −4.75 to −1.00 DS) and −0.31 ± 0.40 DC (range, −1.50 to 0 DC) before ortho-k treatment and −3.39 ± 1.04 DS (range, −5.50 to −1.00 DS) and −0.88 ± 0.50 DC (range, −2.00 to 0 DC) after 37.4 ± 11.9 months of ortho-k treatment followed by one month of lens wear discontinuation, with both changes being statistically significant (both $P < 0.001$).

Corneal curvature along the flatter and steeper meridian changed from 42.84 ± 0.98 D (range, 40.48 to 45.26 D) and 44.00 ± 1.17 D (41.00 to 46.46 D) before ortho-k treatment to 42.62 ± 1.01 D (40.02 to 45.01 D) and 44.06 ± 1.11 D (41.02 to 46.99 D) after discontinuation of ortho-k lens wear, respectively. Compared to baseline, corneal curvature became significantly flatter in the flatter meridian (−0.22 ± 0.27 D, $P < 0.001$) and steeper in the steeper meridian (0.06 ± 0.34 D, $P = 0.032$) after cessation of ortho-k lens wear, resulting in a significant increase in with-the-rule corneal astigmatism (0.28 ± 0.43 D, range −1.23 to 1.50 D, $P < 0.001$), which is associated with an increase in refractive astigmatism (0.57 ± 0.57 D, $r = 0.523$, $P < 0.001$; Figure 1).

The amount of residual corneal flattening in the flatter meridian is significantly affected by the length of ortho-k treatment ($t = -2.965$, $P = 0.004$) and the starting age of ortho-k treatment ($t = 2.841$, $P = 0.005$), but not by spherical or cylindrical refractive error prior to ortho-k (both $P > 0.05$). Younger subjects and those who have had longer ortho-k treatment experienced greater increase in corneal astigmatism after discontinuation of lens wear (Figure 2).

After 1-month discontinuation of ortho-k lens wear, all the 136 subject eyes were refitted with ortho-k lenses, among which 25 switched from original spherical designs to toric designs. Figure 3 shows corneal topography maps before ortho-k treatment and after discontinuation of 2 years lens wear in a representative subject who experienced an increase in corneal toricity and a change in the overall corneal shape.

Before treatment, age, spherical refractive error, flat K, and steep K were similar between the ortho-k group and the historical control group, while cylindrical refractive error and corneal toricity were slightly higher in the control group than in the ortho-k group (Table 1). Over the 2-year course of treatment, the corneal curvature did not significantly change in children wearing spectacle lenses (both meridians, $P > 0.05$). Therefore, the change in corneal toricity was more significant in the ortho-k group (0.28 ± 0.43 D) than in the control group (0.12 ± 0.38 D; $P = 0.001$).

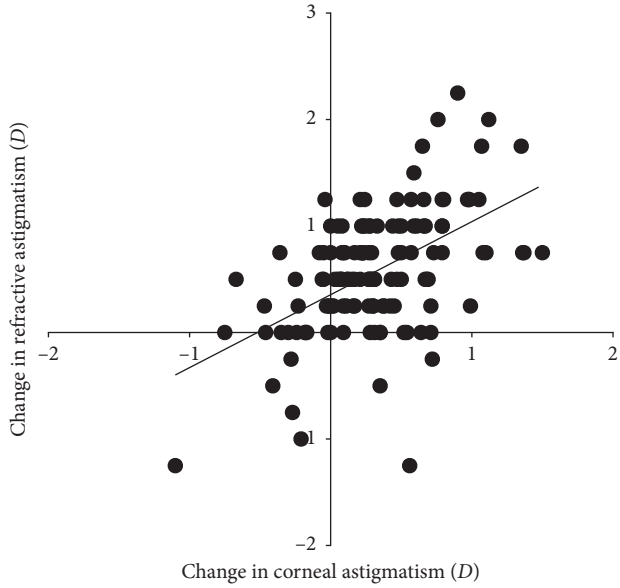


Figure 1: Scatterplots showing the correlation between the change in corneal and refractive astigmatism after discontinuation of ortho-k lens wear as compared to pre-ortho-k value.

4. Discussion

In this study, we found that after long-term ortho-k treatment, the corneal curvature did not fully recover to the baseline level and corneal toricity increased after 1-month discontinuation of ortho-k lens wear. The increase in corneal toricity was associated with an increase in refractive astigmatism.

By treating patients with traditional flat-fitting ortho-k lenses, Kerns [10] reported a significant induction of corneal toricity after prolonged lens wear because the corneal curvature along the steeper meridian became steeper than baseline after lens discontinuation. Increased corneal toricity associated with traditional ortho-k lens wear was mainly caused by significant lens decentration and confounded by low oxygen-permeable lens material related hypoxic corneal effects. In modern orthokeratology, most of the ortho-k lenses being fitted are of high oxygen permeability, well centered, and are supposed to yield relatively even forces to different corneal meridians. Nevertheless, we found a significant change in the corneal curvature after discontinuation of lens wear following long-term ortho-k treatment, despite that a good lens centration had been achieved using reverse-geometry lenses.

While a mean change of 0.28 D in corneal toricity may seem clinically insignificant, noteworthy is that 25 out of 136 subjects had to be refitted ortho-k lenses with midperipheral toric designs after the washout period as opposed to original spherical designs, indicating that their overall anterior corneal shape has been changed in addition to central curvature change. In agreement with our study, Wu et al. [9] found the persistence of a small increase of with-the-rule corneal astigmatism (0.17 D) after discontinuation of reverse geometry ortho-k lens wear, due to a residual corneal flattening in the flatter meridian. The authors also found a trend toward greater residual corneal flattening among subjects with higher pretreatment myopic refractive error. However, the discontinuation period in their study ranged from 7 to 45 days (mean, 17 days), which might be inadequate for the cornea to recover in some of the subjects with shorter period of washout, as indicated by Santodomingo-Rubido et al.'s study [8]. Our study did not find a significant correlation between initial refractive error and residual corneal flattening after a uniform 1-month lens discontinuation, suggesting that ortho-k wearers with higher myopia do not necessarily have to stop lens wear for longer

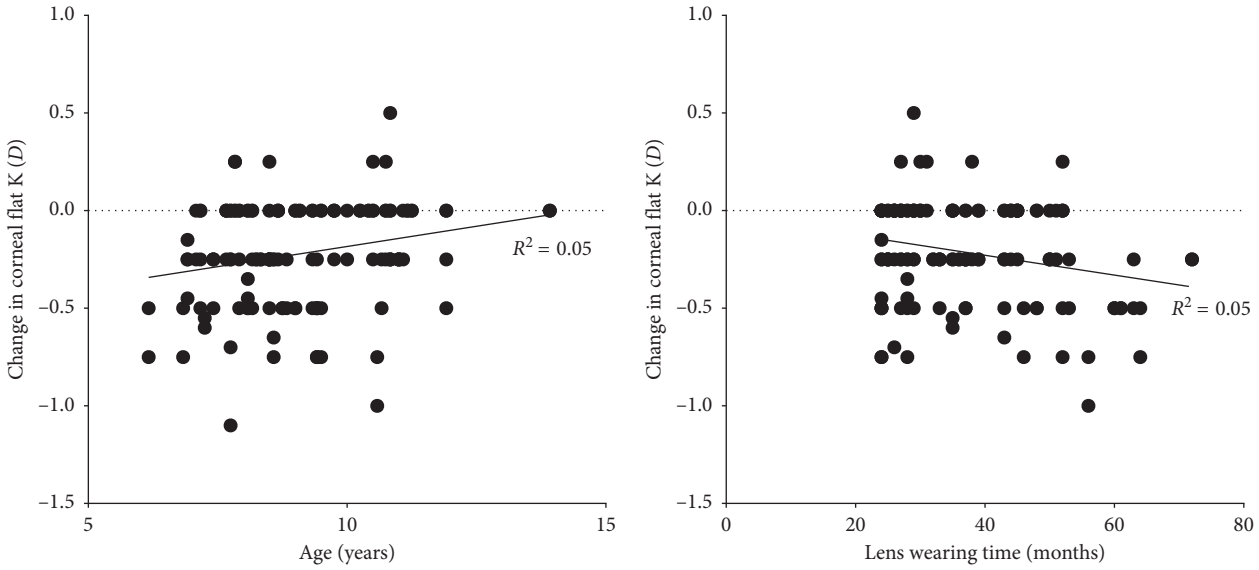


Figure 2: Scatterplots showing the change in corneal flat K after cessation of ortho-k lens wear, in the function of subject's starting age for ortho-k (a) and lens wearing time (b).

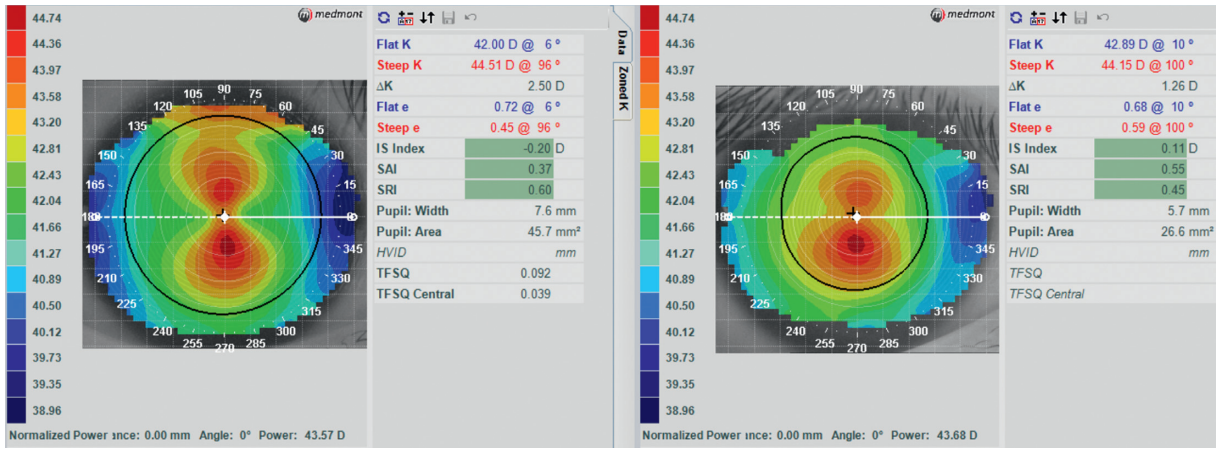


Figure 3: Corneal topography maps from a representative subject who experienced a significant increase in corneal toricity and a change in overall corneal shape in the right eye after discontinuation of ortho-k lens wear (a) as compared to pre-ortho-k value (b).

Table 1: Comparison of refractive error and corneal curvature between the ortho-k and control group.

	OK (n = 136)		SVL (n = 123)		P value
	Mean	SD	Mean	SD	
Pretreatment age	9.1	1.5	9.4	1.8	0.149
Pretreatment sphere	−2.53	1.07	−2.37	1.52	0.336
Pretreatment cylinder	−0.31	0.40	−0.45	0.58	0.024
Pretreatment FK	42.84	0.98	42.84	1.34	0.970
Pretreatment SK	44.00	1.17	44.11	1.57	0.494
Pretreatment toricity	1.16	0.41	1.28	0.57	0.047
Posttreatment FK	42.62	1.01	42.74	1.35	0.430
Posttreatment SK	44.06	1.12	44.14	1.58	0.645
Posttreatment toricity	1.44	0.44	1.40	0.61	0.556
Change in toricity	0.28	0.43	0.12	0.38	0.001

periods for their corneas to recover as compared to their lower myopic counterparts.

Interestingly, our results indicated that age might be an influencing factor for corneal recovery after long-term ortho-k lens wear, although it only explains 5% of the variability. A previous study reported that older subjects (43.9 ± 6.1 years) experienced delayed response to short-term myopic ortho-k treatment. After one hour of lens wear, visual acuity, refraction, and corneal topography changes were significantly less compared to children (9.5 ± 1.7 years) and young adult subjects (24.6 ± 3.7 years) [11]. However, to the best of our knowledge, no studies have investigated the effect of age on corneal biomechanical properties among children aged between 6 and 14 years, but it is possible that physiological changes in a patient's cornea may occur

during long term of ortho-k lens wear, especially in younger children.

Another possible explanation for the incomplete corneal recovery was insufficient lens discontinuation. Kang and Swarbrick [12] recently reported a case, in which a Caucasian female continuously wore ortho-k lenses for 13 years, stopped lens wear for 408 days, and then went for refractive surgery. During the 408 days washout period, the authors found that her corneal curvature almost returned to pre-ortho-k value (about 0.25 D flatter) in one month but did not completely recover until more than one year later. It could be argued that 1-month lens discontinuation might be inadequate in the current study, but it is unlikely for some of the corneas that experienced greater than 1 D increase in corneal toricity to fully recover over time (Figure 2; we actually continued to observe these subjects further but failed to see a significant change even after three months).

Since a more significant residual corneal flattening was observed in the subjects who underwent longer period of ortho-k treatment (Figure 2), it could be argued that the corneal curvature change in children was merely due to an aging effect rather than ortho-k treatment per se. However, data from the spectacle control group are not supportive of this notion: flat K, steep K, and corneal toricity did not significantly change over time in the control group. But given that the observational period was only two years for the control group, as opposed to as long as six years in the ortho-k group, it does not negate the possibility of corneal toricity change in the longer term even in the absence of ortho-k treatment, which warrants further investigation.

It should be noted that all the lenses used in this study were spherical in design, as no limbus-to-limbus corneal astigmatism was present at baseline and spherical lenses have achieved full-correction and good lens centration in all cases. Even if most of the spherical ortho-k lenses were fitted seemingly in alignment with the midperipheral cornea along all the meridians, they could have caused uneven compressive stress on different meridians, being greater in the flatter (horizontal) meridian than in the steeper (vertical) meridian, which in the long term may cause disparate change in corneal physiology between the two meridians. As a result, when being refitted with ortho-k lenses after the discontinuation period, 25 out of 136 subject eyes had a significant increase in corneal toricity and thus needed toric-designed lenses to maintain good lens centration and visual correction. It would be interesting to investigate the long-term effect of toric ortho-k lens wear on the corneal curvature as toric lenses are supposed to induce a more uniform pressure to the mid-peripheral cornea along different meridians when significant corneal toricity is available.

Yang et al. [13] investigated the corneal curvature change in subjects after 24 to 96 months ortho-k treatment followed by 1 to 36 months discontinuation of lens wear, using a mixture of spherical and toric-designed ortho-k lenses. Although they reported no significant change in the corneal curvature after 3 months discontinuation of lens wear as compared to baseline, they did not compare between spherical lens design and toric lens design. Further studies are warranted to investigate the effect of different lens designs on long-term corneal curvature.

In conclusion, this study revealed a significant increase in corneal toricity after long-term ortho-k treatment, and the increase in corneal toricity was associated with an increase in refractive astigmatism. A more pronounced change in corneal toricity was found in subjects who were younger to start ortho-k and have been in a longer period of treatment.

Data Availability

The spreadsheet data used to support the findings of this study are included within the supplementary information files.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Zhi Chen and Jiaqi Zhou contributed equally to this manuscript and are considered co-first authors.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (81700870) and the Shanghai Municipal Health Bureau Research Projects (201540366). The authors thank Shanghai Orthokeratology Study (SOS) Group for assistance in preparation of the paper.

Supplementary Materials

The spreadsheet data contain the baseline refractive error and corneal curvature, the starting age and length of ortho-k treatment, refractive error, and corneal curvature at the end of ortho-k treatment, after cessation of lens wear. (*Supplementary Materials*)

References

[1] H. A. Swarbrick, G. Wong, and D. J. O'Leary, "Corneal response to orthokeratology," *Optometry and Vision Science*, vol. 75, no. 11, pp. 791–799, 1998.

[2] J. J. Nichols, M. M. Marsich, M. Nguyen, J. T. Barr, and M. A. Bullimore, "Overnight orthokeratology," *Optometry and Vision Science*, vol. 77, no. 5, pp. 252–259, 2000.

[3] Y. Zhong, Z. Chen, F. Xue, H. Miao, and X. Zhou, "Central and peripheral corneal power change in myopic orthokeratology and its relationship with 2-year axial length change," *Investigative Ophthalmology and Visual Science*, vol. 56, no. 8, pp. 4514–4519, 2015.

[4] A. Alharbi and H. A. Swarbrick, "The effects of overnight orthokeratology lens wear on corneal thickness," *Investigative Ophthalmology and Visual Science*, vol. 44, no. 6, pp. 2518–2523, 2003.

[5] P. S. Soni, T. T. Nguyen, and J. A. Bonanno, "Overnight orthokeratology: refractive and corneal recovery after discontinuation of reverse-geometry lenses," *Eye and Contact Lens: Science and Clinical Practice*, vol. 30, no. 4, pp. 254–262, 2004.

[6] J. T. Barr, M. J. Rah, W. Meyers, and J. Legerton, "Recovery of refractive error after corneal refractive therapy," *Eye and*

Contact Lens: Science and Clinical Practice, vol. 30, no. 4, pp. 247–251, 2004.

[7] Y. Kobayashi, R. Yanai, N. Chikamoto, T. Chikama, K. Ueda, and T. Nishida, "Reversibility of effects of orthokeratology on visual acuity, refractive error, corneal topography, and contrast sensitivity," *Eye and Contact Lens: Science and Clinical Practice*, vol. 34, no. 4, pp. 224–228, 2008.

[8] J. Santodomingo-Rubido, C. Villa-Collar, B. Gilmartin, and R. Gutierrez-Ortega, "Short-term changes in ocular biometry and refraction after discontinuation of long-term orthokeratology," *Eye and Contact Lens*, vol. 40, no. 2, pp. 84–90, 2014.

[9] R. Wu, F. Stapleton, and H. A. Swarbrick, "Residual corneal flattening after discontinuation of long-term orthokeratology lens wear in Asian children," *Eye and Contact Lens: Science and Clinical Practice*, vol. 35, no. 6, pp. 333–337, 2009.

[10] R. L. Kerns, "Research in orthokeratology. Part V: results and observations—recovery aspects," *Journal of the American Optometric Association*, vol. 48, no. 3, pp. 345–359, 1977.

[11] J. Jayakumar and H. A. Swarbrick, "The effect of age on short-term orthokeratology," *Optometry and Vision Science*, vol. 82, no. 6, pp. 505–511, 2005.

[12] P. Kang and H. Swarbrick, "Discontinuation of long term orthokeratology lens wear and subsequent refractive surgery outcome," *Contact Lens and Anterior Eye*, vol. 40, no. 6, pp. 436–439, 2017.

[13] L. Yang, X. Guo, and P. Xie, "Observation of orthokeratology discontinuation," *Chinese Journal of Ophthalmology*, vol. 51, no. 3, pp. 178–182, 2015.

Hindawi
Journal of Ophthalmology
Volume 2018, Article ID 3174826, 10 pages
https://doi.org/10.1155/2018/3174826

Clinical Study

Changes and Diurnal Variation of Visual Quality after Orthokeratology in Myopic Children

Hao-Chen Guo, Wan-Qing Jin, An-Peng Pan, Qin-Mei Wang, Jia Qu, and A-Yong Yu

The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

Correspondence should be addressed to A-Yong Yu; yaybetter@hotmail.com

Received 16 June 2018; Accepted 18 September 2018; Published 15 October 2018

Academic Editor: José M. Gonzalez-Méijome

Purpose. To assess the changes and the diurnal variation of visual quality after orthokeratology in myopic children. *Methods*. Forty-four eyes of 22 subjects with a mean age of 10.55 ± 1.53 years (8 to 14 years) were enrolled in this prospective study. Their spherical equivalent ranged from −1.25 to −4.25 diopters (D) and astigmatism was less than 1.00 D. Parameters including corneal curvature, ocular objective scatter index (OSI), the modulation transfer function (MTF), root mean square of ocular and corneal wavefront aberrations, and contrast sensitivity function (CSF) were measured before and at two time points during the same day after 1 month of orthokeratology. *Results*. After orthokeratology, uncorrected visual acuity (UCVA) and spherical equivalent were significantly improved from baseline ($P < 0.001$), and their diurnal variation was not significant ($P = 0.083, 0.568$). OSI increased from 0.29 ± 0.15 to 0.65 ± 0.31 ($P < 0.001$). MTF decreased significantly ($P < 0.01$). Corneal curvature and ocular total aberration decreased ($P < 0.001$), while the ocular and corneal higher-order aberration increased significantly ($P < 0.01$). The CSF under photopic condition decreased at 3 cpd ($P = 0.006$) and increased at 18 cpd ($P = 0.012$). The diurnal variation of CSF at 18 cpd under mesopic and high glare conditions and at 12 cpd under photopic condition was significant ($P = 0.002, 0.01, 0.017$). *Conclusions*. Orthokeratology can effectively improve UCVA and high spatial frequency CSF by decreasing the low-order aberrations. However, MTF and CSF at low spatial frequency decreased because of the increase of intraocular scattering and high-order aberrations. Meanwhile, CSF at high spatial frequency fluctuates significantly at two times during the same day after 1 month orthokeratology.

1. Introduction

Orthokeratology involves wearing of specially designed gas-permeable contact lenses which temporarily reshape corneal contour [1]. This procedure can offer patients useful vision during waking hours without involving additional corrective devices, such as spectacles or daily wear contact lenses. However, unstable vision during waking hours, transient light distortion under low-light condition, and dissatisfied night vision were reported by certain patients [2]. Several studies have demonstrated that overnight orthokeratology may increase corneal and ocular higher order aberrations [3–5] and decrease contrast sensitivity function (CSF) [4–6]. Furthermore, several short-term studies have reported that the influence of orthokeratology on refraction and visual acuity gradually diminished during the day once the lens was removed [7–10], which may cause uncomfortable visual experience as mentioned above. These studies focus mostly on wavefront aberration, visual acuity, and refraction. However, these assessments are insufficient to fully understand the effects of orthokeratology on visual quality because retinal image is affected not only by ocular aberration but also by intraocular scattering [11, 12].

Research based on double-pass technique have revealed that the retinal image quality may be overestimated by aberrometric techniques which often failed to take the effect of diffuse light (dispersion or scattering) into account, and the double-pass system has been proven to be a useful tool for comprehensive evaluation of optical quality of the eye because it can provide parameters that included intraocular scattering [12–14]. There were few studies using double-pass technique to evaluate the visual quality after orthokeratology. Jeon et al. [15] used the double-pass system in 13 patients (24 eyes) and found that the intraocular scattering increased after 1 month of orthokeratology lenses wear. However, that study did not involve the diurnal variation of visual quality. Recent studies

suggested that the combined effect of ocular aberration and intraocular scattering on the visual quality was not a simple summation, and the peripheral aberration could compromise partial effect of scattering [16]. The study on contact lenses using the double-pass technique found that corneal swelling caused increased intraocular scattering, resulting in a significant impact on the optical quality of the eye [17]. Currently, limited data were available on the changes and diurnal variation of comprehensive visual quality after orthokeratology in myopic children. This study aimed to provide information on changes and diurnal variation of visual quality after orthokeratology by analyzing the data of refraction, intraocular scattering, corneal topography, wavefront aberration, CSF, and subjective questionnaire. The comprehensive measurements of these changes are essential for a better understanding of the impact of orthokeratology on vision, especially in children.

2. Methods

In this prospective study, 44 eyes of 22 myopic patients (9 boys, 13 girls) with a mean age of 10.55 ± 1.53 yrs (mean ± standard deviation, range: 8 to 14 yrs) were enrolled. Spherical equivalent ranged from −1.25 to −4.25 D (−2.81 ± 0.87 D), and astigmatism was less than 1.00 D (0.48 ± 0.21 D). The best corrected visual acuity (BCVA) was 20/20 or better. After 1 month of orthokeratology, only eyes with an uncorrected visual acuity (UCVA) of 20/20 or better were included. Subjects with a history of contact lens wear or any current ocular or systemic disease such as a significant dry eye, papillary conjunctivitis, keratoconus, corneal dystrophies, and corneal opacities that could affect ocular physiology were excluded. This study was in accordance with the tenets of the Declaration of Helsinki and approved by the Ethics Committee at the Eye Hospital of Wenzhou Medical University. Informed consent was obtained from each subject and patient.

The baseline measurements were taken in both eyes before orthokeratology lens fitting in the morning at the initial visit, including visual acuity (logarithmic visual acuity chart, GB 11533—1989), manifest refraction (Phoroptor, Phorovist 200), corneal curvature (Keratometer, OM-4), noncontact tonometer (Nidek NT-2000), corneal topography (E300 Corneal Topographer), corneal endothelial count (Topcon, SP-2000P), and axial length (IOL-MASTER, Zeiss). For each subject, the best suitable orthokeratology lens was chosen from three brands (Table 1) according to the different fitting situations. The subjects were recommended to wear the lenses 7 nights a week and at least 8 hours per night to ensure the best situation of UCVA. All the subjects were monitored by the same experienced doctor. One month after orthokeratology, the measurements were taken immediately following lens removal in the morning and 8 hours later in the afternoon during the same day. At every visit, all the measurements were taken within 30 minutes to minimize the fluctuation of each parameter.

2.1. Double-Pass Measurements. The objective parameters of optical quality were measured by a double-pass optical quality analysis system (OQAS II, Visiometrics S.L., Tarrasa, Spain). A single light source produced by a 780 nm laser beam adequately filtered and collimated was used as a starting point. The beam image was projected onto the eye retina. When it reflects on the retina, the light crosses the ocular medium twice and OQAS II analyses the size and shape of the reflected point of light [14]. Room illumination was kept low during the measurement to ensure a natural pupil diameter larger than 5 mm without dilation. The measurements were taken with artificial pupil diameters of 3, 4, and 5 mm, respectively. Astigmatism >0.50 D was corrected by using external ophthalmic cylindrical lenses. The main parameters provided by the double-pass system were the modulation transfer function (MTF) cut-off frequency in cycles per degree (cpd), Strehl ratio (SR), OQAS values (OVs) 100%, 20%, and 9%, objective scatter index (OSI), and tear film mean OSI (TFM-OSI). Three consecutive measurements were obtained for each eye and the mean value was calculated.

2.2. Wavefront Aberration Measurements. Wavefront aberrations and treatment zone after orthokeratology were measured with Nidek OPD-Scan III (Nidek Technologies, Gamagori, Japan) (based on automatic retinoscopy; provides integrated corneal topography and wavefront measurement in one device) [18]. Ocular and corneal wavefront aberrations for a 3, 4, or 5 mm optical zone across the undilated pupil were measured. Data were expanded with the normalized Zernike polynomials up to the eighth order. Magnitudes of the coefficients of the Zernike polynomials were represented as the root mean square (RMS). Total aberration, higher-order aberration, third- to eighth-order coefficient, astigmatism, spherical aberration, coma, trefoil, and tetrafoil were measured and analyzed separately. Horizontal and vertical diameters across the center of treatment zone (corneal refractive power within 45.0 D) were measured from the instantaneous map of cornea provided by OPD-Scan III (Figure 1) and the average was used. Measurements were repeated at least five times for each eye, and the three best-focused images were selected. The average values were used for subsequent analysis.

2.3. Contrast Sensitivity Function. CSF was measured under mesopic (2.7 cd/m^2) and photopic (85 cd/m^2) conditions, with and without high glare (CSV-1000E, VectorVision, Greenville Ohio, USA). CSF under mesopic conditions was measured in dark room and first tested without glare and then with glare. The combination of contrast and glare test was performed with halogen glare lights positioned at the sides of the console. The glare lights did not alter the illumination of the console. Monocular measurements were taken at 2.5 m distance with the best spectacle correction before orthokeratology and without correction after orthokeratology. The contrast threshold in logarithmic values for 3, 6, 12, and 18 cpd and the area under the log CSF (AULCSF) were used for subsequent analysis [19].

2.4. Subjective Questionnaire. Quality of Life Impact of Refractive Correction (QIRC) [20] was used to evaluate the

Table 1: The orthokeratology lens parameters in this study.

Brand	E&E	Euclid	Lucid
Origin	China	USA	Korea
Material	Boston XO	Boston equalens II	Boston XO
Dk (cm^2/sec) ($mL \cdot O_2/mL \cdot mmHg$) (ISO/fatt)	$100 * 10^{-11}$	$90 * 10^{-11}$	$140 * 10^{-11}$
The overall diameter (mm)	10.6	10.6	10.6
The optic zone diameter (mm)	6	6.2	6.2
The reverse curve (mm)	0.6	0.5	0.9
The anchor curve (mm)	1.3	1.2	0.8
The peripheral curve (mm)	0.4	0.5	0.5
The central thickness (mm)	0.22	0.22	0.23

subjective vision experience by the same ophthalmologist. Each subject was tested twice separately before and 1 month after orthokeratology.

2.5. Statistical Analysis. All statistical analyses were performed using SPSS 18.0 (SPSS Inc, Chicago, Illinois, USA). All continuous variables were expressed as the mean ± standard deviations (Mean ± SD). The normality of each variable was checked with the 1-sample Kolmogorov-Smirnov test. Comparisons of the parameters before and after orthokeratology and between morning and afternoon on the same day were performed by using a paired t-test. The level of significance was P less than 0.05.

3. Results

Among the 22 children who were enrolled at baseline, 3 of them dropped out of the study because their UCVA did not achieve 20/20 due to the decentration of orthokeratology lens. Among the 19 children, 4 subjects finished partial measurements due to poor cooperation.

One month after orthokeratology, LogMAR UCVA in the morning (−0.066 ± 0.09) was significantly improved from baseline (0.557 ± 0.23, $P < 0.001$) and did not differ from that in the afternoon (0.049 ± 0.05, $P = 0.083$).

Table 2 showed manifest sphere refraction and corneal curvature significantly reduced after orthokeratology ($P < 0.001$). Regular astigmatism did not change significantly ($P = 0.155$). The diurnal variation of corneal curvature was statistically significant ($P < 0.001$), but sphere refraction was not ($P = 0.568$).

One month after orthokeratology, OSI significantly increased from 0.295 ±0.15 to 0.652 ± 0.31 ($P < 0.001$), TFM-OSI increased from 0.572 ± 0.29 to 1.212 ± 0.97 ($P < 0.002$), MTF cut-off, SR, and OVs decreased significantly ($P < 0.033$). The diurnal variation of these parameters was not significant (Table 3).

Tables 4 and 5 showed ocular and corneal aberrations respectively. One month after orthokeratology, ocular total aberration decreased significantly ($P < 0.001$). Ocular higher-order aberration, corneal total aberration, and corneal higher-order aberration increased significantly ($P < 0.01$) (Figures 2 and 3). Ocular and corneal coma, trefoil, tetrafoil, and spherical aberrations for 3, 4, and 5 mm optical zone increased significantly, except the ocular sixth- to eighth-order aberrations for 3 mm optical zone. The

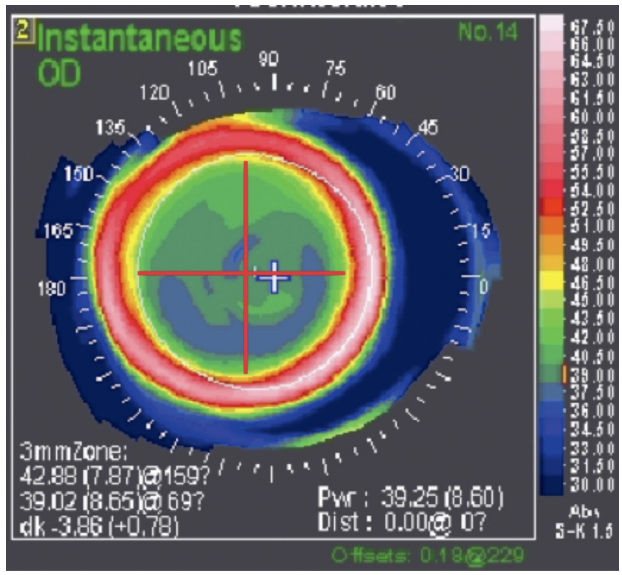


Figure 1: Instantaneous map. *The instantaneous map calculates the corneal curvature radiuses from the shape between the infinitesimal intervals along meridians reflecting more local corneal curvatures (shapes).

Table 2: Effects of orthokeratology on refraction and corneal curvature ($n = 22$ eyes, mean ± SD).

Time	Sphere (D)	Cylinder (D)	K1 (D)	K2 (D)
AM baseline	−3.83 ± 0.97	−0.47 ± 0.43	42.05 ± 1.26	43.19 ± 1.37
AM 1 month	−1.03 ± 0.85	−0.69 ± 0.57	39.75 ± 0.97	40.64 ± 1.27
PM 1 month	−1.10 ± 0.68	−0.66 ± 0.52	40.02 ± 1.05	40.95 ± 1.27
P1	<0.001	0.155	<0.001	<0.001
P2	0.568	0.500	<0.001	<0.001

Paired t-test. P1: comparison between AM baseline and AM 1 month after orthokeratology; P2: comparison between AM and PM during the same day 1 month after orthokeratology; K1: flat keratometric value; K2: steep keratometric value.

diurnal variation of aberrations was not significant, except ocular spherical aberration for 3 mm optical zone ($P = 0.03$). Treatment zone diameters (TZD) decreased from 4.12 ± 0.18 mm to 3.95 ± 0.23 mm ($P = 0.001$), and the average change was 0.16 ± 0.13 mm.

Table 3: Effects of orthokeratology on OSI, TFM-OSI, MTF cut-off, SR, and OVs (n = 22 eyes, mean ± SD).

Time	OSI	TFM-OSI	MTF	SR	OVs-100%	OVs-20%	OVs-9%
3 mm optical zone							
AM baseline	—	—	48.332 ± 8.10	0.309 ± 0.07	1.611 ± 0.27	1.778 ± 0.40	1.922 ± 0.49
AM 1 month	—	—	38.812 ± 9.58	0.225 ± 0.07	1.294 ± 0.32	1.292 ± 0.41	1.316 ± 0.46
PM 1 month	—	—	42.225 ± 8.93	0.250 ± 0.07	1.408 ± 0.30	1.448 ± 0.42	1.489 ± 0.48
P1	—	—	<0.001	<0.001	<0.001	<0.001	<0.001
P2	—	—	0.067	0.064	0.068	0.053	0.068
4 mm optical zone							
AM baseline	0.295 ± 0.15	0.572 ± 0.29	46.089 ± 7.26	0.280 ± 0.05	1.537 ± 0.24	1.652 ± 0.35	1.733 ± 0.38
AM 1 month	0.652 ± 0.31	1.212 ± 0.97	37.312 ± 8.16	0.211 ± 0.05	1.244 ± 0.27	1.216 ± 0.33	1.233 ± 0.35
PM 1 month	0.712 ± 0.43	1.128 ± 0.59	38.856 ± 9.55	0.223 ± 0.06	1.295 ± 0.32	1.300 ± 0.41	1.325 ± 0.45
P1	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
P2	0.239	0.63	0.32	0.169	0.326	0.204	0.189
5 mm optical zone							
AM baseline	—	—	44.812 ± 8.87	0.275 ± 0.06	1.494 ± 0.30	1.602 ± 0.40	1.687 ± 0.46
AM 1 month	—	—	37.174 ± 7.96	0.215 ± 0.05	1.239 ± 0.27	1.209 ± 0.32	1.243 ± 0.36
PM 1 month	—	—	39.124 ± 10.37	0.224 ± 0.06	1.304 ± 0.35	1.322 ± 0.44	1.339 ± 0.44
P1	—	—	0.003	0.001	0.003	0.001	0.001
P2	—	—	0.177	0.294	0.178	0.051	0.109

Paired t-test. P1: comparison between AM baseline and AM 1 month after orthokeratology; P2: comparison between AM and PM during the same day 1 month after orthokeratology.

Table 4: Effects of orthokeratology on ocular aberrations (n = 22 eyes, mean ± SD).

Time	Coma	Trefoil	Tetrafoil	Sph	S3	S4	S5	S6	S7	S8
3 mm optical zone										
Baseline AM	0.019 ± 0.01	0.044 ± 0.02	0.023 ± 0.01	−0.004 ± 0.01	0.050 ± 0.02	0.028 ± 0.01	0.017 ± 0.01	0.017 ± 0.01	0.013 ± 0.01	0.011 ± 0.01
1 month AM	0.049 ± 0.03	0.077 ± 0.04	0.037 ± 0.02	0.019 ± 0.02	0.099 ± 0.04	0.050 ± 0.02	0.029 ± 0.02	0.025 ± 0.02	0.018 ± 0.01	0.015 ± 0.01
1 month PM	0.052 ± 0.03	0.081 ± 0.05	0.030 ± 0.03	0.023 ± 0.01	0.101 ± 0.06	0.046 ± 0.03	0.027 ± 0.02	0.019 ± 0.01	0.015 ± 0.01	0.013 ± 0.01
P1	<0.001	0.002	0.005	<0.001	<0.001	<0.001	<0.001	0.11	0.081	0.235
P2	0.618	0.665	0.216	0.03	0.799	0.331	0.752	0.233	0.409	0.428
4 mm optical zone										
Baseline AM	0.043 ± 0.02	0.081 ± 0.03	0.035 ± 0.02	−0.010 ± 0.02	0.095 ± 0.03	0.047 ± 0.02	0.033 ± 0.01	0.028 ± 0.01	0.022 ± 0.01	0.018 ± 0.01
1 month AM	0.196 ± 0.09	0.136 ± 0.08	0.072 ± 0.03	0.099 ± 0.06	0.256 ± 0.10	0.143 ± 0.06	0.087 ± 0.04	0.060 ± 0.03	0.039 ± 0.03	0.033 ± 0.03
1 month PM	0.210 ± 0.08	0.145 ± 0.08	0.062 ± 0.05	0.108 ± 0.04	0.264 ± 0.10	0.141 ± 0.06	0.083 ± 0.05	0.046 ± 0.02	0.031 ± 0.02	0.026 ± 0.02
P1	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.007	0.017
P2	0.158	0.634	0.417	0.14	0.587	0.839	0.672	0.116	0.282	0.329
5 mm optical zone										
Baseline AM	0.091 ± 0.05	0.129 ± 0.04	0.059 ± 0.03	−0.019 ± 0.05	0.166 ± 0.05	0.091 ± 0.04	0.064 ± 0.03	0.047 ± 0.03	0.039 ± 0.02	0.032 ± 0.02
1 month AM	0.532 ± 0.26	0.223 ± 0.10	0.120 ± 0.06	0.333 ± 0.16	0.603 ± 0.26	0.393 ± 0.15	0.181 ± 0.09	0.112 ± 0.05	0.082 ± 0.05	0.065 ± 0.04
1 month PM	0.540 ± 0.24	0.222 ± 0.10	0.093 ± 0.07	0.328 ± 0.14	0.602 ± 0.24	0.373 ± 0.14	0.157 ± 0.08	0.095 ± 0.05	0.074 ± 0.04	0.051 ± 0.03
P1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002
P2	0.762	0.969	0.181	0.73	0.968	0.224	0.238	0.233	0.536	0.213

Paired t-test. P1: comparison between AM baseline and AM 1 month after orthokeratology; P2: comparison between AM and PM during the same day 1 month after orthokeratology.

Changes in AULCSF under mesopic, photopic, and high glare conditions were not statistically significant before and after orthokeratology. The log CSF under photopic condition increased at 18 cpd (P = 0.012), but decreased at 3 cpd (P = 0.006). AULCSF under high glare and photopic conditions, log CSF at 18 cpd under mesopic and high glare conditions, log CSF at 12 cpd under photopic condition all increased significantly in the

Table 5: Effects of orthokeratology on corneal aberrations (n = 22 eyes, mean ± SD).

Time	Coma	Trefoil	Tetrafoil	Sph	S3	S4	S5	S6	S7	S8
3 mm optical zone										
Baseline	0.048 ±	0.143 ±	0.105 ±	0.009 ±	0.155 ±	0.140 ±	0.091 ±	0.102 ±	0.063 ±	0.071 ±
AM	0.02	0.05	0.05	0.01	0.05	0.05	0.03	0.03	0.02	0.02
1 month	0.120 ±	0.210 ±	0.171 ±	0.026 ±	0.251 ±	0.243 ±	0.162 ±	0.184 ±	0.104 ±	0.129 ±
AM	0.09	0.14	0.10	0.03	0.16	0.16	0.10	0.12	0.06	0.09
1 month	0.109 ±	0.202 ±	0.170 ±	0.027 ±	0.242 ±	0.235 ±	0.149 ±	0.176 ±	0.097 ±	0.123 ±
PM	0.11	0.14	0.09	0.02	0.17	0.15	0.10	0.12	0.07	0.09
P1	0.002	0.047	0.011	0.003	0.015	0.005	0.005	0.003	0.01	0.004
P2	0.663	0.836	0.946	0.924	0.825	0.81	0.616	0.77	0.666	0.761
4 mm optical zone										
Baseline	0.121 ±	0.452 ±	0.310 ±	0.038 ±	0.482 ±	0.413 ±	0.335 ±	0.314 ±	0.278 ±	0.221 ±
AM	0.05	0.21	0.11	0.02	0.19	0.12	0.11	0.09	0.12	0.06
1 month	0.534 ±	0.673 ±	0.604 ±	0.198 ±	0.903 ±	0.820 ±	0.657 ±	0.641 ±	0.468 ±	0.440 ±
AM	0.39	0.42	0.35	0.17	0.53	0.46	0.32	0.35	0.26	0.24
1 month	0.409 ±	0.561 ±	0.494 ±	0.200 ±	0.733 ±	0.696 ±	0.555 ±	0.533 ±	0.365 ±	0.357 ±
PM	0.40	0.31	0.34	0.10	0.49	0.43	0.30	0.38	0.25	0.21
P1	<0.001	0.036	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	0.004	<0.001
P2	0.056	0.192	0.181	0.923	0.101	0.237	0.12	0.192	0.055	0.149
5 mm optical zone										
Baseline	0.411 ±	0.439 ±	0.330 ±	0.099 ±	0.668 ±	0.490 ±	0.645 ±	0.366 ±	0.497 ±	0.253 ±
AM	0.37	0.39	0.32	0.15	0.46	0.45	0.45	0.30	0.27	0.20
1 month	1.016 ±	1.175 ±	0.858 ±	0.451 ±	1.644 ±	1.454 ±	1.412 ±	1.266 ±	1.205 ±	1.042 ±
AM	0.42	0.66	0.53	0.33	0.62	0.67	0.69	0.84	0.83	0.59
1 month	1.231 ±	0.956 ±	0.738 ±	0.408 ±	1.629 ±	1.388 ±	1.182 ±	0.993 ±	0.918 ±	0.823 ±
PM	1.39	1.12	0.71	0.37	1.77	1.38	1.28	0.99	0.92	0.89
P1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
P2	0.474	0.443	0.528	0.636	0.971	0.844	0.485	0.346	0.296	0.292

Paired t-test. P1: comparison between AM baseline and AM 1 month after orthokeratology; P2: comparison between AM and PM during the same day 1 month after orthokeratology.

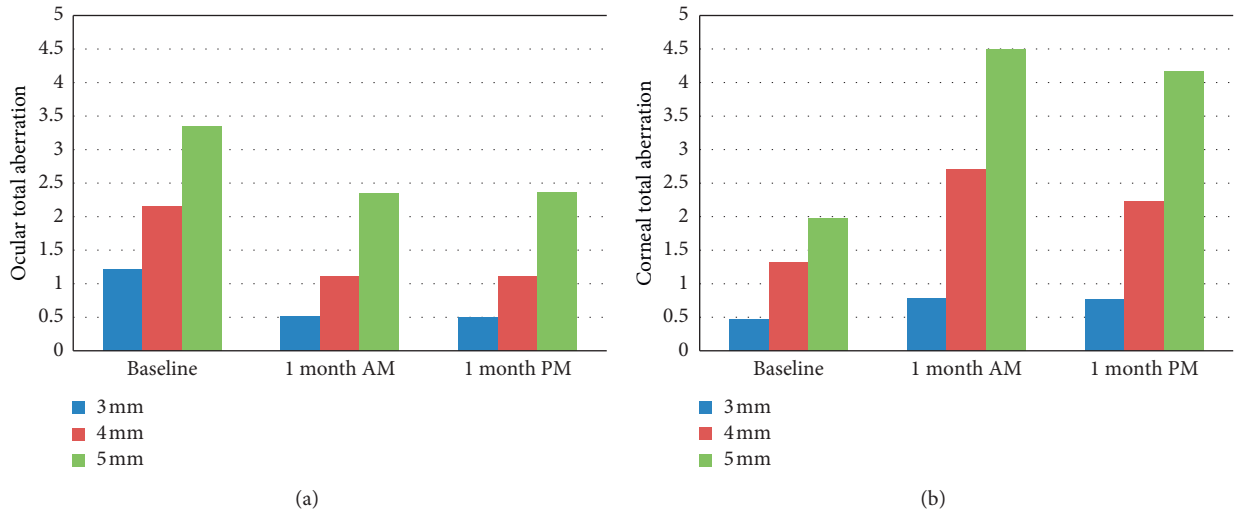


Figure 2: Effects of orthokeratology on ocular and corneal total aberrations (n = 22 eyes).

afternoon compared to the parameters in the morning at 1 month. Besides the above mentioned, no significant diurnal variation was found for other parameters of CSF (Table 6).

The survey of the subjective questionnaire showed that the dry eye symptom was more remarkable after orthokeratology (P = 0.03), nevertheless the feeling of asthenopia was relieved (P = 0.01). The mean score of satisfaction to orthokeratology was 92.25. During the whole day and night, self-reported vision was stable in 10 children (45%), 1 subject (5%) had a fluctuating vision, and 11 children (50%) reported that the vision in the morning was better than that in the evening.

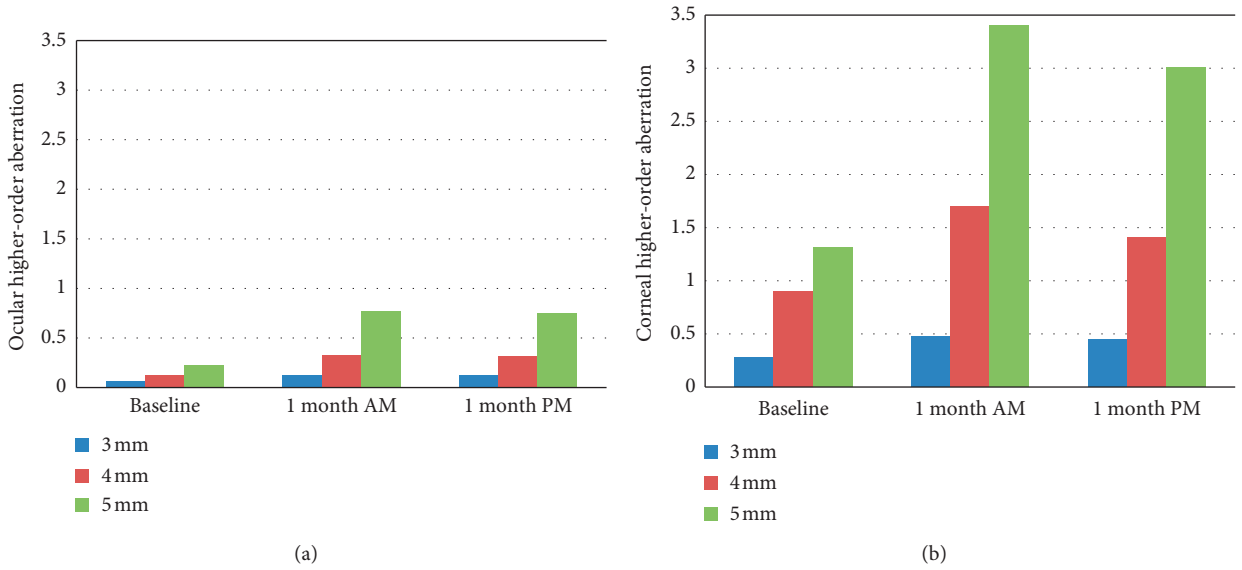


Figure 3: Effects of orthokeratology on ocular and corneal higher-order aberrations ($n = 22$ eyes).

Table 6: Effects of orthokeratology on contrast sensitive function ($n = 22$ eyes, mean ± SD).

Time	3 cpd	6 cpd	12 cpd	18 cpd	AULCSF
			Mesopic		
AM baseline	1.620 ± 0.19	1.677 ± 0.17	1.552 ± 0.21	1.266 ± 0.37	1.245 ± 0.10
AM 1 month	1.606 ± 0.16	1.700 ± 0.26	1.573 ± 0.29	1.272 ± 0.36	1.257 ± 0.16
PM 1 month	1.632 ± 0.12	1.706 ± 0.21	1.551 ± 0.34	1.408 ± 0.38	1.267 ± 0.15
P1	0.706	0.634	0.7	0.913	0.659
P2	0.342	0.87	0.654	0.002	0.655
			High glare		
AM baseline	1.636 ± 0.25	1.686 ± 0.24	1.483 ± 0.25	1.267 ± 0.37	1.235 ± 0.13
AM 1 month	1.577 ± 0.20	1.669 ± 0.32	1.517 ± 0.28	1.338 ± 0.35	1.235 ± 0.19
PM 1 month	1.613 ± 0.18	1.746 ± 0.22	1.562 ± 0.31	1.431 ± 0.38	1.285 ± 0.14
P1	0.19	0.787	0.514	0.233	0.992
P2	0.387	0.086	0.226	0.01	0.018
			Photopic		
AM baseline	1.722 ± 0.17	1.657 ± 0.21	1.57 ± 0.29	1.266 ± 0.36	1.251 ± 0.13
AM 1 month	1.631 ± 0.14	1.716 ± 0.28	1.59 ± 0.27	1.397 ± 0.37	1.279 ± 0.17
PM 1 month	1.678 ± 0.14	1.775 ± 0.19	1.67 ± 0.22	1.430 ± 0.38	1.326 ± 0.11
P1	0.006	0.317	0.746	0.012	0.431
P2	0.115	0.129	0.017	0.371	0.01

Paired t-test. P1: comparison between AM baseline and AM 1 month after orthokeratology; P2: comparison between AM and PM during the same day 1 month after orthokeratology.

4. Discussion

Orthokeratology can reduce the refractive error by remodeling the anterior surface of cornea temporarily [21]. With the improvement of refraction, the low-order aberrations, which constituted 80%~85% of the ocular total aberration, reduced. Therefore, UCVA could be 20/20 or better after orthokeratology, as demonstrated in this study that most children whose best corrected visual acuity were 20/20 with spectacles before orthokeratology achieved 20/20 or better UCVA after 1 month of orthokeratology. Some research [22–24] indicated that orthokeratology could improve UCVA effectively. In addition, the increase of high spatial frequency CSF may be due to the improvement of UCVA after 1 month of orthokeratology because the high spatial frequency CSF mainly reflected the central macular vision. Furthermore, the improvement of vision and self-confidence after removal of spectacles as psychological and physiological factors may play a role. Nichols et al. [25] discovered that the changes of visual and refractive outcomes became stable around 1 month after orthokeratology. Soni et al. [23] even indicated that full effect of orthokeratology was achieved by the end of 1 week and remain stable for all waking hours of the day. Kang et al. [26] demonstrated that cornea experienced regression of correcting effects in the initial period of orthokeratology. This regression caused

decline of visual acuity in the afternoon as corneal asphericity returns. However, the diurnal variation stabilized by 1 month. According to our results, the area of treatment zone at PM was smaller than that at AM, suggesting that the cornea had shape regression. Also, the diurnal variation of corneal curvature was statistically significant. However, the mean diurnal variation of flat and steep corneal curvature within 8 hours after lens removal was 0.27 D and 0.31 D, respectively. Taking into account that the axial length of normal eyes in the afternoon is shorter than that in the morning [27], the extent of diurnal variation of corneal shape after 1 month of orthokeratology had no influence on either manifest refraction or UCVA, indicating that orthokeratology was effective to improve UCVA and the effect was stable after 1 month of lens wear in myopic children.

However, the objective measurements revealed that the optical quality declined after orthokeratology. The value of MTF cut-off, SR, and OVs decreased. Overnight orthokeratology may cause midperipheral stromal thickening [28]. De Juan et al. [17] demonstrated that corneal swelling had a significant impact on the optical quality of the eye. The OSI significantly increased after orthokeratology. Jeon et al. [15] found that OSI increased after orthokeratology but still less than 1.0 on average, which is within the normal range [29]. This was consistent with our results and indicated that the visual quality can remain relatively good despite the slight increasing of intraocular scattering after orthokeratology. In our study, the mean value of OSI for all the myopic children was 0.29 ± 0.15 before orthokeratology, which was better than the result reported by Martínez-Roda et al. (0.38 ± 0.19) [29]. This may be due to the discrepancy of age distribution between the two studies. The intraocular scatter usually increased with age [30]. Furthermore, the TFM-OSI increased, illustrating that the stability of tear film decreased after orthokeratology. The results of subjective questionnaire survey also demonstrated that orthokeratology increases dry eye symptoms (photophobia, dryness, etc.). The stability of tear film also influenced the visual quality.

Ocular higher-order aberration, corneal total aberration, and corneal higher-order aberration increased after orthokeratology in this study. This was consistent with the previously published studies [4, 6, 31]. Corneal refractive therapy significantly increased spherical aberration in the positive direction with an impact on visual quality [32], which was also consistent with our results. It was reported that contrast sensitivity function after orthokeratology deteriorated in proportion to the increases in higher-order aberration [4]. As a consequence, the low spatial frequency CSF decreased, especially the decrease of log CSF at 3 cpd had statistical significance. The decrease of low spatial frequency CSF may be due to the midperipheral corneal steepening in the process of wearing orthokeratology, which affected the imaging function of peripheral retina. Hiraoka et al. [4] researched a group of myopic adults (46 eyes of 23 patients) undergoing overnight orthokeratology and evaluated the change of CSF. They found that orthokeratology treatment resulted in statistically significant decrease of CSF at all spatial frequencies, and AULCSF was significantly reduced from 1.451 ± 0.120 to 1.291 ± 0.177 ($P < 0.0001$). In the present study, the decrease of low spatial frequency CSF was consistent with the result of Hiraoka et al., but we found that AULCSF increased after orthokeratology and the high spatial frequency CSF increased in accordance with the improved UCVA [33]. Hiraoka et al. [34] mentioned that decentered orthokeratology lens could result in decreased CSF after treatment. All the subjects in our study who finished the follow-up were well fitted without obvious decentration of orthokeratology lenses, and this maybe the reason why the AULCSF did not decrease in this study. This indicated that orthokeratology influenced the low spatial frequency CSF, but did not compromise and even improve the high spatial frequency CSF. Lee et al. [35] reported that there were no statistically proved correlations between higher order aberrations and optical quality parameters (MTF cut-off and SR) for adults after refractive surgery. Whether the parameters of the myopic children with orthokeratology have the same outcomes needs further investigations.

In previous research, the corneal thickness [36], axial length, and intraocular pressure [37] showed diurnal changes in human eyes without orthokeratology treatment. Chakraborty et al. [38] indicated that ocular spherical aberration underwent statistically significant diurnal variation, i.e., spherical aberration was positive during the day and gradually became more negative toward the later afternoon/evening. They also found that the anterior corneal curvature was the flattest in the morning and gradually became steeper throughout the day, which led to a significant myopic refractive shift in spherical equivalent refraction later in the day, but it had an apparent paradoxical relationship with the fluctuation in axial length [27] (the longest axial length during the day and the shortest at night). All these physiological fluctuations may result in a compounded effect of visual quality in myopic children with orthokeratology treatment. In our study, the diurnal changes of objective parameters that already included the compounded influence of physiological fluctuations were stable. For 3 mm optical zone at 1 month, though the diurnal variation of ocular spherical aberration was significant ($0.019 \pm 0.016\,\mu$m AM and $0.023 \pm 0.011\,\mu$m PM, $P = 0.03$), corneal spherical aberration had no significant difference between the two time points. This indicated that the change of ocular spherical aberration was not induced by cornea. Furthermore, the corneal higher-order aberration had no change between the two time points. However, the parameter of the range beyond 5 mm was not measured, so the slight change in the central 3 mm optical zone could not exclude the effect of the change of corneal shape beyond 5 mm range. Berntsen et al. [6] studied 20 myopic adults and found that the change of spherical aberration did not play an important role in the increasing of higher-order aberration for a 3 mm pupil. So we inferred that the diurnal change of spherical aberration might have no clinical significance. The CSF at 1 month PM was slightly better than that at 1 month AM, especially the high spatial frequency CSF increased significantly. This may be due to the quick disappearance of corneal edema after lens

removal [10, 17], while the refractive regression was not significant in the afternoon.

The change of optical quality of orthokeratology was a combination of the reduced refraction, the increased intraocular scattering, and the change of ocular and corneal aberrations. Any of the factors was independent and also interrelated to influence the different spatial frequency of CSF and UCVA. David et al. [39] suggested that LASIK provided better visual quality outcomes than orthokeratology for the treatment of low-to-moderate myopia. For myopic adults, considering exclusively the visual quality results, LASIK was a better treatment option than orthokeratology. However, the ablation procedure of refractive surgery may increase ocular scattering [35] and the procedure was irreversible. For myopic children, whose eyes had not yet stopped growing, orthokeratology would be the better choice because the effect of orthokeratology was reversible with regard to optical quality of the eye [40] and the corneal morphology [41]. Furthermore, orthokeratology was a safe option for myopia retardation [42]. Queiros et al. [43] found that orthokeratology achieved the best score among the four treatments (LASIK, spectacle, soft contact lens, and orthokeratology) in the satisfaction for correction and appearance. In the present study, the subjective questionnaire survey on myopic children after orthokeratology indicated that the satisfaction was relatively high, and only three of the children had a transient complaint of light distortion. Santolaria Sanz et al. [44] reported that light distortion tends to return to baseline after one week of treatment, suggesting that neural adaptation is capable of overcoming optical quality degradation. However, still 50% of children consciously thought night vision was worse compared to the vision in the morning and 1 subject (5%) had a fluctuating vision. According to our results, the value of MTF cut-off, SR, and OVs decreased and the high-order aberrations increased with the expanding of pupil diameter. This indicated that visual quality descends under dark environment with larger pupil. The poor night vision may due to the combined effects of more refractive regression and larger pupil diameter at night. More aberration and scattering also resulted in the decrease of the nighttime visual quality. This study did not involve the visual quality at night and the continuous change within the 8 hours during the day was not assessed. Further research was needed to investigate the relationship between the dynamic change of cornea and the change of visual quality after orthokeratology. As the visual quality after orthokeratology was a result of multiple factors, we should not only see the advantage that it can improve UCVA and control the progress of myopia but also consider the declined visual quality and the discomfort complained by children after orthokeratology. Scientific and objective attitude toward the popularity of orthokeratology could serve the clinical practice better.

5. Conclusions

Orthokeratology can effectively improve UCVA and high spatial frequency CSF by decreasing the low-order aberrations. However, MTF and CSF at low spatial frequency decreased because of the increase of intraocular scattering and high-order aberrations. Meanwhile, CSF at high spatial frequency fluctuates significantly at two times during the same day after 1 month orthokeratology. All these significant influence on children's vision provided valuable clues for future lens design and clinical practice.

Disclosure

Drs. Hao-Chen Guo and Wan-Qing Jin are co-first authors of the article. Portions of the data were previously presented in a poster form at the 120th Annual AOA Congress and 47th Annual AOSA Conference: Optometry's Meeting, Washington, DC, June 21–25, 2017 (http://docplayer.net/53226091-poster-presentations-120th-annual-aoa-congress-47th-annual-aosa-conference-optometry-s-meeting.html).

Conflicts of Interest

The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

Acknowledgments

This study is based on the work funded by Zhejiang Provincial Foundation of China for Distinguished Young Talents in Medicine and Health under Grant No. 2010QNA018 and Zhejiang Provincial Natural Science Foundation of China under Grant No. LY14H120007.

References

[1] H. A. Swarbrick, "Orthokeratology review and update," *Clinical and Experimental Optometry*, vol. 89, no. 3, pp. 124–143, 2006.

[2] E. Santolaria, A. Cervino, A. Queiros, R. Brautaset, and J. M. Gonzalez-Meijome, "Subjective satisfaction in long-term orthokeratology patients," *Eye & Contact Lens: Science & Clinical Practice*, vol. 39, no. 6, pp. 388–393, 2013.

[3] T. Hiraoka, A. Furuya, Y. Matsumoto et al., "Quantitative evaluation of regular and irregular corneal astigmatism in patients having overnight orthokeratology," *Journal of Cataract & Refractive Surgery*, vol. 30, no. 7, pp. 1425–1429, 2004.

[4] T. Hiraoka, C. Okamoto, Y. Ishii, T. Kakita, and T. Oshika, "Contrast sensitivity function and ocular higher-order aberrations following overnight orthokeratology," *Investigative Opthalmology & Visual Science*, vol. 48, no. 2, pp. 550–556, 2007.

[5] P. Gifford, M. Li, H. Lu, J. Miu, M. Panjaya, and H. A. Swarbrick, "Corneal versus ocular aberrations after overnight orthokeratology," *Optometry and Vision Science*, vol. 90, no. 5, pp. 439–447, 2013.

[6] D. A. Berntsen, J. T. Barr, and G. L. Mitchell, "The effect of overnight contact lens corneal reshaping on higher-order aberrations and best-corrected visual acuity," *Optometry and Vision Science*, vol. 82, no. 6, pp. 490–497, 2005.

[7] L. Sorbara, D. Fonn, T. Simpson, F. Lu, and R. Kort, "Reduction of myopia from corneal refractive therapy," *Optometry and Vision Science*, vol. 82, no. 6, pp. 512–518, 2005.

[8] J. T. Barr, M. J. Rah, W. Meyers, and J. Legerton, "Recovery of refractive error after corneal refractive therapy," *Eye &*

Contact Lens: Science & Clinical Practice, vol. 30, no. 4, pp. 247–251, 2004.

[9] P. S. Soni, T. T. Nguyen, and J. A. Bonanno, "Overnight orthokeratology: refractive and corneal recovery after discontinuation of reverse-geometry lenses," *Eye & Contact Lens: Science & Clinical Practice*, vol. 30, no. 4, pp. 254–262, 2004.

[10] S. Haque, D. Fonn, T. Simpson, and L. Jones, "Corneal and epithelial thickness changes after 4 weeks of overnight corneal refractive therapy lens wear, measured with optical coherence tomography," *Eye & Contact Lens: Science & Clinical Practice*, vol. 30, no. 4, pp. 189–193, 2004.

[11] P. Artal, "Understanding aberrations by using double-pass techniques," *Journal of Refractive Surgery*, vol. 16, no. 5, pp. S560–S562, 2000.

[12] F. Diaz-Douton, A. Benito, J. Pujol, M. Arjona, J. L. Gu¨ell, and P. Artal, "Comparison of the retinal image quality with a Hartmann-Shack wavefront sensor and a double-pass instrument," *Investigative Opthalmology & Visual Science*, vol. 47, no. 4, pp. 1710–1716, 2006.

[13] J. Santamaria, P. Artal, and J. Bescos, "Determination of the point-spread function of human eyes using a hybrid optical-digital method," *Journal of the Optical Society of America A*, vol. 4, no. 6, pp. 1109–1114, 1987.

[14] C. C. Xu, T. Xue, Q. M. Wang, Y.-N. Zhou, J.-H. Huang, and A.-Y. Yu, "Repeatability and reproducibility of a double-pass optical quality analysis device," *PLoS One*, vol. 10, no. 2, Article ID e0117587, 2015.

[15] H. M. Jeon, D. S. Ahn, D. J. Lee, S. J. Moon, and K. H. Lee, "The effects of overnight orthokeratology lens wear on ocular scatter," *Journal of the Korean Ophthalmological Society*, vol. 55, no. 11, p. 1595, 2014.

[16] G. M. Perez, S. Manzanera, and P. Artal, "Impact of scattering and spherical aberration in contrast sensitivity," *Journal of Vision*, vol. 9, no. 3, p. 19, 2009.

[17] V. De Juan, M. Aldaba, R. Martin, M. Vilaseca, J. M. Herreras, and J. Pujol, "Optical quality and intraocular scattering assessed with a double-pass system in eyes with contact lens induced corneal swelling," *Contact Lens and Anterior Eye*, vol. 37, no. 4, pp. 278–284, 2014.

[18] J. B. Won, S. W. Kim, E. K. Kim, B. J. Ha, and T.-I. Kim, "Comparison of internal and total optical aberrations for 2 aberrometers: iTrace and OPD scan," *Korean Journal of Ophthalmology*, vol. 22, no. 4, p. 210, 2008.

[19] R. A. Applegate, H. C. Howland, R. P. Sharp, A. J. Cottingham, and R. W. Yee, "Corneal aberrations and visual performance after radial keratotomy," *Journal of Refractive Surgery*, vol. 14, no. 4, pp. 397–407, 1998.

[20] K. Pesudovs, E. Garamendi, and D. B. Elliott, "The quality of life impact of refractive correction (QIRC) questionnaire: development and validation," *Optometry and Vision Science*, vol. 81, no. 10, pp. 769–777, 2004.

[21] A. Alharbi and H. A. Swarbrick, "The effects of overnight orthokeratology lens wear on corneal thickness," *Investigative Opthalmology & Visual Science*, vol. 44, no. 6, pp. 2518–2523, 2003.

[22] I. G. Stillitano, M. R. Chalita, P. Schor et al., "Corneal changes and wavefront analysis after orthokeratology fitting test," *American Journal of Ophthalmology*, vol. 144, no. 3, pp. 378–386, 2007.

[23] P. S. Soni, T. T. Nguyen, and J. A. Bonanno, "Overnight orthokeratology: visual and corneal changes," *Eye & Contact Lens: Science & Clinical Practice*, vol. 29, no. 3, pp. 137–145, 2003.

[24] K. L. Johnson, L. G. Carney, J. A. Mountford, M. J. Collins, S. Cluff, and P. K. Collins, "Visual performance after overnight orthokeratology," *Contact Lens and Anterior Eye*, vol. 30, no. 1, pp. 29–36, 2007.

[25] J. J. Nichols, M. M. Marsich, M. Nguyen, J. T. Barr, and M. A. Bullimore, "Overnight orthokeratology," *Optometry and Vision Science*, vol. 77, no. 5, pp. 252–259, 2000.

[26] S. Y. Kang, B. K. Kim, and Y. J. Byun, "Sustainability of orthokeratology as demonstrated by corneal topography," *Korean Journal of Ophthalmology*, vol. 21, no. 2, pp. 74–78, 2007.

[27] R. Chakraborty, S. A. Read, and M. J. Collins, "Diurnal variations in axial length, choroidal thickness, intraocular pressure, and ocular biometrics," *Investigative Opthalmology & Visual Science*, vol. 52, no. 8, pp. 5121–5129, 2011.

[28] A. Alharbi, D. La Hood, and H. A. Swarbrick, "Overnight orthokeratology lens wear can inhibit the central stromal edema response," *Investigative Opthalmology & Visual Science*, vol. 46, no. 7, pp. 2334–2340, 2005.

[29] J. A. Martinez-Roda, M. Vilaseca, J. C. Ondategui et al., "Optical quality and intraocular scattering in a healthy young population," *Clinical and Experimental Optometry*, vol. 94, no. 2, pp. 223–229, 2011.

[30] K. Kamiya, K. Umeda, H. Kobashi, K. Shimizu, T. Kawamorita, and H. Uozato, "Effect of aging on optical quality and intraocular scattering using the double-pass instrument," *Current Eye Research*, vol. 37, no. 10, pp. 884–888, 2012.

[31] T. Hiraoka, Y. Matsumoto, F. Okamoto et al., "Corneal higher-order aberrations induced by overnight orthokeratology," *American Journal of Ophthalmology*, vol. 139, no. 3, pp. 429–436, 2005.

[32] A. Queiros, C. Villa-Collar, J. M. Gonzalez-Meijome, J. Jorge, and A. R. Gutierrez, "Effect of pupil size on corneal aberrations before and after standard laser in situ keratomileusis, custom laser in situ keratomileusis, and corneal refractive therapy," *American Journal of Ophthalmology*, vol. 150, no. 1, pp. 97e1–109e1, 2010.

[33] R. Montes-Mico and W. N. Charman, "Choice of spatial frequency for contrast sensitivity evaluation after corneal refractive surgery," *Journal of Refractive Surgery*, vol. 17, no. 6, pp. 646–651, 2001.

[34] T. Hiraoka, T. Mihashi, C. Okamoto, F. Okamoto, Y. Hirohara, and T. Oshika, "Influence of induced decentered orthokeratology lens on ocular higher-order wavefront aberrations and contrast sensitivity function," *Journal of Cataract & Refractive Surgery*, vol. 35, no. 11, pp. 1918–1926, 2009.

[35] K. Lee, J. M. Ahn, E. K. Kim, and T. I. Kim, "Comparison of optical quality parameters and ocular aberrations after wavefront-guided laser in-situ keratomileusis versus wavefront-guided laser epithelial keratomileusis for myopia," *Graefe's Archive for Clinical and Experimental Ophthalmology*, vol. 251, no. 9, pp. 2163–2169, 2013.

[36] C. L. Harper, M. E. Boulton, D. Bennett et al., "Diurnal variations in human corneal thickness," *British Journal of Ophthalmology*, vol. 80, no. 12, pp. 1068–1072, 1996.

[37] S. A. Read, M. J. Collins, and D. R. Iskander, "Diurnal variation of axial length, intraocular pressure, and anterior eye biometrics," *Investigative Opthalmology & Visual Science*, vol. 49, no. 7, pp. 2911–2918, 2008.

[38] R. Chakraborty, S. A. Read, and M. J. Collins, "Diurnal variations in ocular aberrations of human eyes," *Current Eye Research*, vol. 39, no. 3, pp. 271–281, 2014.

[39] M. C. David, G. Santiago, A. D. Cesar, F. B. Teresa, and M. M. Robert, "Visual quality differences between orthokeratology and LASIK to compensate low-moderate myopia," *Cornea*, vol. 32, no. 8, pp. 1137–1141, 2013.

[40] T. Hiraoka, C. Okamoto, Y. Ishii, F. Okamoto, and T. Oshika, "Recovery of corneal irregular astigmatism, ocular higher-order aberrations, and contrast sensitivity after discontinuation of overnight orthokeratology," *British Journal of Ophthalmology*, vol. 93, no. 2, pp. 203–208, 2009.

[41] L. Yang, X. Guo, and P. Xie, "Observation of orthokeratology discontinuation," *Chinese Journal of Ophthalmology*, vol. 51, no. 3, pp. 178–182, 2015.

[42] Y. M. Liu and P. Xie, "The safety of orthokeratology-a systematic review," *Eye & Contact Lens: Science & Clinical Practice*, vol. 42, no. 1, pp. 35–42, 2016.

[43] A. Queiros, C. Villa-Collar, A. R. Gutierrez, J. Jorge, and J. M. Gonzalez-Meijome, "Quality of life of myopic subjects with different methods of visual correction using the NEI RQL-42 questionnaire," *Eye & Contact Lens: Science & Clinical Practice*, vol. 38, no. 2, pp. 116–121, 2012.

[44] E. S. Sanz, A. Cervino, A. Queiros, C. Villa-Collar, D. Lopes-Ferreira, and J. M. González-Méijome, "Short-term changes in light distortion in orthokeratology subjects," *BioMed Research International*, vol. 2015, Article ID 278425, 7 pages, 2015.