Pentacam findings after implantation of intrastromal corneal rings in keratoconus

Hebatullah S. G. Shaltout, Hany O. Elsedfy, Abd EL.Nasser Awade, Magdi M. Mostafa, Mahmoud Abdel- Radi

Ophthalmology, Department of Ophthalmology, Assiut University Hospital, Assiut, Egypt

Correspondence to Hebatullah S. G. Shaltout, M.Sc., Ophthamlology, Assistant Lecturer of Ophthalmology, Faculty of Medicine, Assiut University Hospital, Assiut, Egypt.
Tel: +201014719253
e-mail: heba94shaltout@aun.edu.eg

Received 18 July 2023
Revised 18 August 2023
Accepted 21 August 2023
Published 23 December 2023

Journal of Current Medical Research and Practice
2023, 8:207–213

Introduction
Intrastromal corneal ring segment implantation is a minimally invasive procedure. Its main goals are to flatten and regularize the cornea, to improve uncorrected and corrected visual acuity, and to delay or even prevent a keratoplasty. ICRSs effect correlates directly to its thickness and inversely to its distance to the visual axis.

Patients and methods
A retrospective observational study involving 44 eyes of 44 patients was initiated. The files and pentacam printouts of 44 patients were retrospectively extracted and evaluated. The preoperative and postoperative ocular findings and pentacam parameters of anterior and posterior corneal surfaces, in addition to the pachymetry data, were recorded and analyzed.

Results
Forty-four patients with keratoconus were evaluated in this study. Evaluation of anterior corneal surface showed significant flattening of all keratometry readings ($P < 0.001$) with significant improvement of corneal astigmatism ($P = 0.03$), corneal asphercity ($P < 0.001$), the inferior-superior asymmetry ($P = 0.019$) and the front elevation ($P = 0.005$) The posterior corneal surface showed significant improvement in back elevation ($P < 0.001$), and the back surface asphercity showed significant prolate shift ($P = 0.01$). The thinnest location was significantly upward displaced towards the corneal apex. kera 355° showed a significant flattening of all keratometry readings with significant improvement of corneal astigmatism and corneal asphercity of the anterior corneal surface and the back surface asphercity showed significant prolate shift ($P = 0.001$). The ICRS showed a significant flattening of k_m ($P = 0.030$) and corneal asphercity of the anterior corneal surface ($P = 0.046$).

Conclusion
The intracorneal ring implantation led to improvement of the tomographic corneal parameters which was more significant at the anterior corneal surface.

Keywords:
intrastromal corneal rings, keratoconus, pentacam findings

J Curr Med Res Pract 8:207–213

2357-0121

Introduction

keratoconus is a progressive corneal ectatic disease characterized by paraxial stromal thinning and weakening, resulting in irregular astigmatism, corneal protrusion, and distortion of the anterior corneal surface. It is usually bilateral, although asymmetrical in most cases [1]. The management of keratoconus depends on its severity, in early stage, spectacles or soft contact lenses may be effective but in mild to moderate stage rigid gas-permeable contact lenses (RGPCLs) and scleral RGPCLs that cover the entire cornea are required. Also, corneal collagen cross-linking (CXL) and intracorneal rings (ICRs) are effective. Furthermore, keratoplasty is confined for severe and advanced stage with impaired vision who could not use contact lenses [2]. Intrastromal corneal rings implantation is safe and reversible procedure that does not affect the central corneal area, and hence, avoids interference with visual axis. The goal of intrastromal corneal rings implantation is to improve visual acuity by reguliztion of the anterior corneal surface [3]. Intrastromal corneal ring segment implantation is a minimally invasive procedure. Its main goals are to flatten and regularize the cornea, to improve uncorrected and corrected visual acuity, and to delay or even prevent a keratoplasty. ICRSs effect correlates directly to its thickness and inversely to its distance to the visual axis [4]. The aim of the study is to correlate the effect of intra-corneal ring segment with the age of the patients and to evaluate the tomographic changes that occur at the anterior and posterior corneal surfaces after intrastromal corneal rings implantation.

Patients and methods

This was a retrospective observational case series study that included 44 eyes of 44 patients were selected from El NOUR Eye Center, Assiut government, Eygpt. All patients were subjected to full ophthalmological examination including examination of the cornea and anterior segment at the slit-lamp, fundus biomicrosopy, (intra ocular pressure) IOP, (uncorrected visual acuity) UCVA, (distant corrected visual acuity) DCVA, manifest and subjective refraction were extracted from patients files and records. The study was approved by the Institutional Review Board\Ethics Committee of the Faculty of Medicine at Assiut University with IRB 17101543, and was conducted in accordance with Declaration of Helsinki. This study included patients with keratoconus implanted with the KeraRing 355 degree, KeraRing one segment and KeraRing two segments ICRS. Corneal tomography scans of the two corneal surfaces were obtained preoperatively and postoperatively with a rotating Scheimpflug imaging system, pentacam (Pentacam HR; Oculus, Wetzlar, Germany). The study participants underwent evaluation of the anterior and posterior surface parameters, Pachymetry parameters, elevation maps parameters and the effect of Kera 355° ring and ring segments on anterior and posterior corneal surfaces

Inclusion criteria

The patients included in this study were cases of keratoconus grade II and III according to the mean K Amsler-Krumeich classification, aged more than 18 year old, their corneal thinnest location is more than 400 um, Their maximum keratometry (Kmax) between 48 and 62 D, with contact lens intolerance and clear cornea with no Vogt's striae.

Exclusion criteria

Cases of corneal scarring, patients had previous corneal surgery, patient with Grade IV KC, any concurrent corneal disease in addition to KC and patients with autoimmune or systemic connective tissue diseases were excluded from the study.

Surgical technique

We first do preoperative preperations by application of topical anathesia using Benoxate hydrochlroide 4% sterile ophthalmic eye drops (Benox; Egyptian International pharmaceutical Industries Co., 10th of Ramadan city, Eygpt), complete aseptic conditions by using iodine eye drop 5% and drapping the eye then pupil center is marked at the site of the light reflex as a reference point and corneal thickness is measured at the site of implantaion and femtosecond laser docking system is adjusted. femtosecond laser eliminate the precorneal tear film, applanate the cornea, fixates the eye, and maintains a precise distance from the head of the laser to the focal point of the tunnel location**.** Femtosecond laser system (FS-200 wavelight; Fort Worth, USA). The device use 200-kHz repetition rate, 1030-nm wave length. The selection of ICRS was according to the manufacturer nomogram keraRing 355°(Mediphacos, Belo Horizonte, Brazil)) offered for central keratoconus and mainly myopic refractive error. The femtosecond laser is used with 5-μm spot size to create an intrastromal corneal pocket of 8-mm diameter and a depth of nearly 80% of the corneal thickness at the thinnest location with a superior tunnel incision at 90° of 4-mm width, Kera ring segments offered for patients presented mainly with astigmatic error, a tunnel is made, the incision is reopened with Sinsky hooks, forceps are used to grasp the intra-corneal ring segment and lift it from its case. the ring segment is rolled slightly superiorly to achieve the proper entry angle, once the leading edge is inserted into the pocket and half of the segment is in the tunnel, the grasp on the forceps is released the reminder of the segment is then nudged into the tunnel using the Sinsky hook and finally, application of contact lens. Postoperative medications: include tobramycin eye drops and dexamethasone eye drops five times per day for two weeks.

Statistical analysis

The Statistical Package for the Social Sciences (version 25.0; SPSS, Inc., Chicago, IL) was used for the statistical analysis. The results are presented as mean ± standard deviation. For comparison of groups, the Wilcoxon test for nonparametric samples was used. For correlation, the Pearson's correlation coefficient was used. *P* values of less than. 05 were considered statistically significant.

Results

This study included 44 eyes of 44 patients with keratoconus who underwent intra-corneal ring implantation, 26 of them were males and 18 were females (Table 1).

Table 1 Patient demographics

Variables	Patients (*n*=44)	
Age		
Mean±SD	24.95±5.10	
Median (IQR)	24 (23–26)	
Gender *n* (%)		
Male	26	59.1%
Female	18	40.9%
Residence *n* (%)		
Rural	27	61.4%
Urban	17	38.6%
History of consanguinity *n* (%)	31	70.5%

Values are presented as mean±SD or number (%)

The anterior surface

The mean postoperative (flat keratometry readings) K_1, (steep keratometry reading) K_2 and (maximum keratomety reading) K_m showed a statistically significant flattening from the preoperative values. The mean postoperative K_{max} was found to be significantly flat. The mean corneal astigmatism significantly decreased postoperatively. There was a statistically significant decrease in the prolatness of the corna. The asymmetric inferior steepening relation to superior (I-S) at 4 mm circle showed significant decrease (Table 2).

The posterior surface

The mean k_1, k_2 and k_{max} showed non-significant flattening postoperatively. Corneal astigmatism showed non-significant decrease in amplitude. Q-value showed statistically significant prolate shift (Table 3).

Pachymetry parameters

The mean pachymetry at corneal apex at thinnest location as well as the mean average progression index showed non-significant increase. The pachymetry at the thinnest location increased, while the average progression index increased. The mean corneal volume,

Table 2 Preoperative and postoperative anterior surface parameters

Variables	Keratoconus patients (*n*=44)			*P*
	Preoperative	Postoperative	Change (Δ)	
K_1				
Mean±SD	47.1±3.6	44.5±5.2	−2.6±4.57	<0.001*
Median (IQR)	46.5 (46–48.2)	44 (42.9–46.1)	−2.95 (−4–1.23)	
K_2				
Mean±SD	51.5±5	48.6±6.1	−2.93±5.07	<0.001*
Median (IQR)	50.7 (50–53)	47.8 (46.7–50.4)	−3.4 (−4.48–1.39)	
K_m				
Mean±SD	49.3±4.3	46.3±5.3	−3.03±4.77	<0.001*
Median (IQR)	48.4 (48–50.6)	46 (44.6–47.9)	−3.65 (−4.48–1.58)	
K_{max}				
Mean±SD	56±6.72	54.7±6.87	−1.26±3.56	0.023*
Median (IQR)	55.45 (53.99–58.08)	53.66 (52.68–56.87)	0.00 (−0.1–2.34)	
Corneal astig				
Mean±SD	−2.2±4.6	−1.4±4.5	0.8±2.36	0.03*
Median (IQR)	−3.3 (−3.6–0.8)	−2.5 (−2.7–0.03)	0.9 (0.08–1.5)	
Q-value				
Mean±SD	−1±0.8	−0.28±1.14	0.7±1.18	<0.001*
Median (IQR)	−0.96 (−1.27–0.75)	−0.19 (−0.6–0.06)	0.79 (0.3–1.09)	
Sagittal curvature map (I-S at (4 mm))				
Mean±SD	7.7±4.5	6.4±4.2	−1.26±3.45	0.019*
Median (IQR)	8.4 (6.3–9.1)	7 (5.1–7.7)	−0.85 (−2.3–0.20)	

Values are presented as mean±SD and median (IQR) K_1, flat keratometry reading; K_2, steep keratometry reading; K_m, mean keratometry reading; k_{max}, maximum keratometry reading; astig, corneal astigmatism; *P* value , is significant if <0.05.

Table 3 Preoperative and postoperative posterior surface parameters

Variables	Preoperative	Postoperative	change (Δ)	*P*
K_1				
Mean±SD	−7.1±1.2	−7±0.9	−0.008±0.98	0.95
Median (IQR)	−7.1(−7.4–6.7)	−7(−7.3–6.8)	0.1 (−0.3–0.2)	
K_2				
Mean±SD	−8.0±0.9	−7.7±1.2	0.17±0.72	0.1
Median (IQR)	−7.9(−8.0–7.6)	−7.8(−8.1–7.4)	0.05(−0.04–0.3)	
K_m				
Mean±SD	−7.6±0.8	−7.4±1.1	0.15±0.62	0.11
Median (IQR)	−7.4 (−7.8–7.3)	−7.4(−7.7–7.0)	0.1(−0.3–0.03)	
Corneal astig				
Mean±SD	0.7±0.6	0.5±0.78	−0.15±0.62	0.12
Median (IQR)	0.8 (0.5–0.9)	0.7 (0.3–0.8)	0.00(−0.3–0.04)	
Q-value				
Mean±SD	−1.41±0.82	−1.65±0.82	−0.24±0.61	0.01*
Median (IQR)	−1.23 (−1.66–1.16)	−1.53(−1.90–1.40)	−0.27(−0.42–0.05)	

Values are presented as mean±SD and median (IQR) K_1, flat keratometry reading; K_2, steep keratometry reading; K_m, mean keratometry reading; kmax, maximum keratometry reading; astig, corneal astigmatism; *P* value, is significant if <0.05.

on the other hand, showed significant increase, and the mean vertical downward displacement of the thinnest location showed significant improvement (Table 4).

Elevation map parameters

The mean values of front and back elevations showed a significant decrease. (Table 5).

Correlation between age and change (Δ) in K1 and K2 at the anterior surface

There was a statistically significant, negative moderate correlation between the age of patients and the amplitude of flattening effect of ICRS on k_1. On the other hand, we found no correlation between the age of patients and the amplitude of change in $_{Kmax}$ and corneal volume (Table 6) (Figs. 1 and 2).

The effect of Kera 355° and segment rings on the anterior surface parameter

The Kera 355° ring resulted in significant flattening effect on the mean k_1, and the mean k_2, the Kera 355° ring resulted in a statistically significant oblate shift On the other hand, there was no significant decrease in the mean corneal astigmatism. The corneal ring segments resulted in a statistically significant flattening effect on the mean k_m and a statistically significant oblate shift. the ring segments led to non-significant flattening effect on the mean k_1 and mean k_2. and led to non-significant decrease in the mean corneal astigmatism (Table 7).

The effect of Kera 355° and segment rings on the posterior surface parameters

The Kera 355° ring resulted in a statistically significant prolate shift in asphericity of posterior corneal surface. On the other hand, Kera 355°ring did not result in significant change in the mean k_1 nor in the mean corneal astigmatism. The corneal ring segments led to non-significant change in all posterior corneal surface parameters (Table 8).

Discussion

In the current study, the mean age of patients at presentation was 24.45 ± 5.10 years, which was consistent with previous studies [5,6]. Buzzonetti and his colleagues suggested that KC commonly appears in teens or early 20 $_s$ of age, but can present later in life especially when mild [7]. We found a statistically significant flattening of all K-readings of anterior corneal surface. Similar results were

Table 4 Preoperative and postoperative pachymetry parameters

Variables	Keratoconus patients (*n*=44)			*P*
	Preoperative	Postoperative	Change (Δ)	
At apex				
Mean±SD	450±36	451s41	0.43±30.35	0.925
Median (IQR)	448.5 (440–461)	457 (439–464)	5.00 (–8.7–9.6)	
Thinnest location				
Mean±SD	443±37	446±41	2.72±29.3	0.541
Median (IQR)	439 (432–455)	450 (434–459)	6.00 (–6.1–11.6)	
Y- co-ordinate				
Mean±SD	–0.27±0.21	–0.12±0.25	0.14±0.27	0.001*
Median (IQR)	–0.25 (–0.33–0.2)	–0.07 (–0.2–0.04)	0.13 (0.06–0.22)	
Corneal volume				
Mean±SD	56.77±3.9	57.44±4.17	0.67±2.36	0.002*
Median (IQR)	56.20 (55.58–57.95)	56.3 (56.17–58.71)	0.00 (–0.04–1.3)	
Average progression index				
Mean±SD	2.51±0.88	3.18±1.22	0.66±1.34	0.067
Median (IQR)	2.37 (2.24–2.78)	3.11 (2.81–3.55)	0.31 (0.25–1.07)	

Values are presented as mean±SD and median (IQR). **P* value is significant if <0.05.

Table 5 Preoperative and postoperative elevation map parameters

Variables	Keratoconus patients (*n*=44)			*P*
	Preoperative	Postoperative	Change (Δ)	
Elevation map (Front elevation)				
Mean±SD	16.8±11.2	11.29±12.2	-5.5±12.44	0.005*
Median (IQR)	18 (13.3–20.2)	8 (7.5–15)	–7.00 (–9.2–1.7)	
Elevation map (back elevation)				
Mean±SD	43±17	41±16	–1.75±3.06	<0.001*
Median (IQR)	47 (38–49)	44 (36–46)	–1.00 (–2.68–0.81)	

Values are presented as mean±SD and median (IQR). **P* value is significant if <0.05.

Table 6 Correlation between age and change (Δ) in K1 and K2 anterior surface

Variables	Age	
	r value	*P* value
Change (Δ) in K_1	-0.344	0.022
Change (Δ) in K_2	-0.347	0.021
Change (Δ) K_{max}	0.12	0.437
Change (Δ) in corneal volume	-0.062	0.687

Values are presented as mean ± SD. **P* value is significant if <0.05

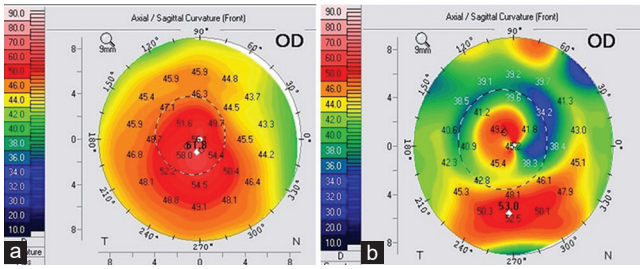
Table 7 Preoperative and postoperative anterior surface parameters according to the type of ring (kera 355 and segment rings)

Variables	Kera 355° ring (*n*=23)	Segment ring (*n*=21)
K_1 Mean±SD		
Preoperative	47.2±3.35	47.1±4.1
Postoperative	43.7±4.38	45.4±6.0
Change (Δ)	−3.35±4.23	−1.61±4.81
Percent of change (Δ)	7%	3%
P value within group	0.001*	0.139
K_2 Mean±SD		
Preoperative	51.3±4.3	51.8±5.8
Postoperative	45.8±4.7	49.5±7.4
Change (Δ)	−3.55±4.72	−2.26±5.47
Percent of change (Δ)	6%	4%
P value within group	0.002*	0.073
K_m Mean±SD		
Preoperative	49.19±3.7	49.5±5.0
Postoperative	46.7±4.3	46.9±6.3
Change (Δ)	−3.4±4.47	−2.63±5.16
Percent of change (Δ)	6%	5%
P value within group	0.001*	0.030*
Corneal astig Mean±SD		
Preoperative	−2.4±3.8	−1.9±5.4
Postoperative	−1.6±3.8	−1.2±5.2
Change (Δ)	0.84±2.67	0.75±2.05
Percent of change (Δ)	35%	39%
P value within group	0.142	0.108
Q-value Mean±SD		
Preoperative	−1.05±0.73	−0.97±0.99
Postoperative	−0.18±1.2	−0.39±1.09
Change (Δ)	0.87±1.11	0.58±1.26
Percent of change (Δ)	82%	59%
P value within group	0.001*	0.046*

Values are presented as mean±SD and median (IQR) K_1, flat keratometry reading; K_2, steep keratometry reading; K_m, mean keratometry reading; k_{max}, maximum keratometry reading; astig, corneal astigmatism; *P* value , is significant if <0.05.

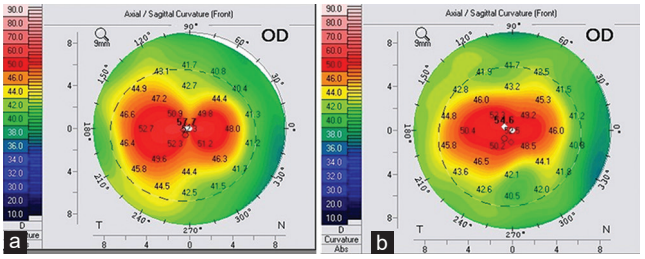
reported in previous studies [5,8–14]. The Q-value showed significant oblate shift indicating significant improvement of anterior surface asphericity, likewise, the anterior corneal surface astigmatism significantly improved. These results were consistent with a study by Lyra in 2017 [15]. For the posterior corneal surface, we found non-significant improvement in keratometric readings and corneal astigmatism. On the contrary, Sedaghat *et al.* [16] reported significant improvement of K-readings and corneal astigmatism except for the mean keratometry reading and Q-value which didn't show significant oblate shift, But we found that the Q-value significantly changed towards prolate shift. A possible explanation for this might be that ICRSs affect the back surface of the cornea as well. It is known that keratoconic corneas have a local forward protrusion on both the anterior and posterior surfaces. Furthermore, the optical contribution of the posterior corneal surface is considerably more significant in keratoconus, particularly in advanced cases by D'Oria *et al.*, [17]. Another explanation is one might also expect a significant change in posterior corneal curvature; however, the observed changes showed the most flattening effect in the anterior corneal surface in the group with successful results. This flattening effect is explainable based on the arc-shortening model, which supposes that the ring segments act as spacers between the corneal lamellae and consequently will reduce the arc length of the central lamellae These findings confirm the findings of Pérez-Merino *et al.* [18] and Ortiz *et al.* [19]. According to the Pachymetry Parameters, in our study the values at the corneal apex, at the thinnest location as well as the mean average progression index showed non-significant increase. The mean corneal volume, On the other hand, showed significant increase and the mean vertical displacement of the thinnest location showed significant improvement. These results are in agreement with Sedaghat *et al.* [20], this study showed that there was no statistically significant difference between pre- and postoperative corneal thickness measurements at the apex, in the thinnest point [16]. On the other hand, there was a statistically significant increase in pachymetry postoperatively in all age groups as noticed by Torquetti *et al.* [21]. In our study the elevation maps parameters showed a significant decrease in the values of the front and back elevation. This finding is consistent with, a study found that the maximum elevation points on the anterior and posterior surfaces of the cornea decreased significantly, with the posterior surface experiencing a greater elevation decline as noticed by Abd Elaziz *et al.* [8], and supported by reports by Rho *et al.* [22], and Salgado-Bovges *et al.* [23]. In our study, we found that the amplitude of flattening of k_1 and k_2 was significantly related to the age of the patient where the greater flattening was found in younger age patient.On comparing the effect of Kera 355° ring with ring segments on anterior surface parameters: the Kera 355° ring resulted in statistically significant flattening effect on the mean k_1, k_2 and k_m. while the corneal ring segments flattened all the K-readings, this flattening was significant only on the mean k_m. Both types of rings have resulted in improvement of the amplitude of anterior corneal astigmatism that was statistically non-significant. On the other hand, both types produced a statistically significant oblate shift in corneal asphericity that was more pronounced

Figure 1



(a) Preoperative and (b) postoperative refractive map of 20 year old patient.

Figure 2



(a) Preoperative and (b) postoperative refractive map of 42 year old patient.

Table 8 Preoperative and postoperative posterior surface parameters according to the type of ring

Variables	Kera 355° ring (*n*=23)	Segment ring (*n*=21)
K_1 Mean±SD		
Preoperative	−7.12±0.7	−7±1.6
Postoperative	−7.2±0.8	−6.9±0.95
Change (Δ)	−0.07±0.51	0.06±1.33
Percent of change (Δ)	0.9%	0.8%
P value within group	0.499	0.830
K_2 Mean±SD		
Preoperative	−8.0±0.8	−8.0±1.0
Postoperative	−7.8±1.2	−7.8±1.3
Change (Δ)	0.13±0.61	0.23±0.83
Percent of change (Δ)	1.6%	2.8%
P value within group	0.324	0.215
Km Mean±SD		
Preoperative	−7.5±0.8	−7.6±0.9
Postoperative	−7.3±1.0	−7.4±1.2
Change (Δ)	0.07±0.58	0.23±0.67
Percent of change (Δ)	0.9%	3%
P value within group	0.529	0.125
Corneal astig Mean±SD		
Preoperative	0.8±0.5	0.6±0.8
Postoperative	0.6±0.6	0.5±1.0
Change (Δ)	−0.2±0.5	−0.10±0.76
P value within group	25%	16%
P value within group	0.067	0.570
Q-value Mean±SD		
Preoperative	−1.29±0.84	−1.54±0.81
Postoperative	−1.69±0.86	−1.61±0.79
Change (Δ)	−0.39±0.65	−0.08±0.52
Percent of change (Δ)	30%	5%
P value within group	0.009*	0.498

Values are presented as mean±SD and median (IQR) K_1, flat keratometry reading; K_2, steep keratometry reading; K_m, mean keratometry reading; k_{max}, maximum keratometry reading; astig, corneal astigmatism; *P* value , is significant if <0.05.

with Kera 355° ring type. The effects of corneal ring segments on the anterior surface parameters were a flattening in all K-readings and this flattening only significant on the mean km, the improvement in the amplitude of corneal astigmatism was statistically non-significant and a statistically significant oblate shift in the corneal asphericity of the anterior surface and these results are consistent with that reported by berty *et al*. While the effects of corneal ring segments on the posterior surface parameters were a non-significant postoperative difference in the mean k1, k2, km, or in the posterior corneal surface astigmatism and a statistically non-significant oblate shift in the corneal asphericity and this consistent with Berty *et al*. [24]

Conclusion

The intracorneal ring implantation led to improvement of the tomographic corneal parameters which was more significant at the anterior corneal surface.

Financial support and sponsorship

Nil

Conflicts of interest

There are no conflicts of interest.

References

1 Belin MW, Duncan JK. Keratoconus: The ABCD Grading System. Klin Monbl Augenheilkd 2016; 233:701–7.

2 Ismail MM, Elsedfy HO, Abdelazeem K, Aly MA. Effect of femtosecond-assisted intrastromal implantation of MyoRing for keratoconus on corneal asphericity. Delta J Ophthalmol 2019; 20:17.

3 Sakellaris D, Balidis M, Gorou O, Szentmary N, Alexoudis A, Grieshaber MC, *et al*. Intracorneal ring segment implantation in the management of Keratoconus: An evidence-based approach. Ophthalmol Ther 2019; 8(Suppl 1):5–14.

4 Hernández-Quintela E, Sánchez-Huerta V, García-Albisua A, Gulias-Cañizo R. Preoperative evaluation of keratoconus and ectasia. Refract Surg E-Book 2019:170.

5 Shetty R, Matalia H, Srivatsa P, Ghosh A, Dupps JrWJ, Roy AS. A novel Zernike application to differentiate between three-dimensional corneal thickness of normal corneas and corneas with keratoconus. Am J Ophthalmol 2015; 160:453–62. e2

6 Sinjab MM. *Step by Step: Reading Pentacam Topography: Basics and Clinical Applications*. ■: JP Medical Ltd; 2020.

7 Buzzonetti L, Bohringer D, Liskova P, Lang S, Valente P. Keratoconus in Children: A literature review. Cornea 2020; 39:1592–8.

8 Abd Elaziz MS, Sarhan ARES, Ibrahim AM, Haggag HAE. Anterior segment changes after femtosecond laser-assisted implantation of a 355-degree intrastromal corneal ring segment in advanced keratoconus. Cornea 2018; 37:1438–43.

9 Abdellah MM, Ammar HG. Femtosecond laser implantation of a 355-degree

intrastromal corneal ring segment in keratoconus: a three-year follow-up. J Ophthalmol 2019; 2019:■.

10 Jadidi K, Mosavi SA, Nejat F, Naderi M, Janani L, Serahati S. Intrastromal corneal ring segment implantation (keraring 355 degrees) in patients with central keratoconus: 6-month follow-up. J Ophthalmol 2015; 2015:916385.

11 Ambrósio R, Faria Correia F, Belin MW. *Analyzing tomographic thickness for detecting corneal ectatic diseases*. ■: Keratoconus: Recent Advances in Diagnosis and Treatment. 2017. p. 77–85.

12 Gokhale NS. Epidemiology of keratoconus. Indian J Ophthalmol 2013; 61:382.

13 Ziaei H, Jafarinasab MR, Javadi MA, Karimian F, Poorsalman H, Mahdavi M, *et al*. Epidemiology of keratoconus in an Iranian population. Cornea 2012; 31:1044–7.

14 Haddad JS, Barnwell E, Rocha KM, Waring IVGO. First clinical impressions on the integrated corneal tomography and corneal deformation with scheimpflug imaging. Int J Keratoconus Ectatic Corneal Dis 2017; 6:101–9.

15 Lyra JM, Lyra D, Ribeiro G, Torquetti L, Ferrara P, Machado A. Tomographic findings after implantation of ferrara intrastromal corneal ring segments in Keratoconus. J Refract Surg 2017; 33:110–5.

16 Sedaghat MR, Momeni-Moghaddam H, Belin MW, Zarei-Ghanavati S, Akbarzadeh R, Sabzi F, *et al*. Changes in the ABCD keratoconus grade after intracorneal ring segment implantation. Cornea 2018; 37:1431–7.

17 D'Oria F, Bagaglia SA, Alio Del Barrio JL, Alessio G, Alio JL, Mazzotta C. Refractive surgical correction and treatment of keratoconus. Surv Ophthalmol 2024; 69:122–39.

18 Pérez-Merino P, Ortiz S, Alejandre N, Jiménez-Alfaro I, Marcos S. Quantitative OCT-based longitudinal evaluation of intracorneal ring segment implantation in keratoconus. Investig Ophthalmol Vis Sci 2013; 54:6040–51.

19 Ortiz S, Pérez-Merino P, Alejandre N, Gambra E, Jimenez-Alfaro I, Marcos S. Quantitative OCT-based corneal topography in keratoconus with intracorneal ring segments. Biomed Opt Express 2012; 3:814–24.

20 Sedaghat MR, Momeni-Moghaddam H, Pinero DP, Akbarzadeh R, Moshirfar M, Bamdad S, *et al*. Predictors of successful outcome following intrastromal corneal ring segments implantation. Curr Eye Res 2019; 44:707–15.

21 Torquetti L, Ferrara G, Ferrara P. Predictors of clinical outcomes after intrastromal corneal ring segments implantation. Int J Keratoconus Ectatic Corneal Dis 2012; 1:26–30.

22 Rho CR, Na KS, Yoo YS, Pandey C, Park CW, Joo CK. Changes in anterior and posterior corneal parameters in patients with keratoconus after intrastromal corneal-ring segment implantation. Curr Eye Res 2013; 38:843–50.

23 Salgado-Borges JM, Costa-Ferreira C, Monteiro M, Guilherme-Monteiro J. Refractive, tomographic and biomechanical outcomes after implantation of ferrara ICRS in keratoconus patients. Int J Keratoconus Ectatic Corneal Dis 2013; 1:16–21.

24 Berty M, Eliwa T, Gaafar A, Mousa A. Effect of intracorneal ring segments on posterior corneal topography in eyes with keratoconus. Archivos de la Sociedad Española de Oftalmología (English Edition) 2022; 97:424–31.