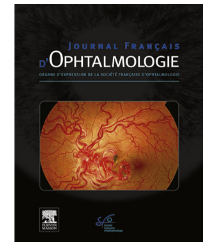
Journal français d'ophtalmologie 46 (2023) 510—517

Disponible en ligne sur

Elsevier Masson France

EM|consulte

www.em-consulte.com



ORIGINAL ARTICLE

Asymmetric intracorneal ring segments in the treatment of snowman phenotype keratoconus

Segments d'anneaux intracornéens asymétriques dans le traitement du kératocone de phénotype bonhomme de neige.

E. Coskunseven[a,b], **B. Kayhan**[a,c,*]

[a] *Département de chirurgie réfractive, hôpital Dunyagoz Etiler, Istanbul, Turkey*
[b] *Faculté des sciences de la santé, université Rumeli d'Istanbul, Istanbul, Turkey*
[c] *Département d'ophtalmologie, Sultan II, hôpital de formation et de recherche Abdulhamid Han, université des sciences de la santé, Istanbul, Turkey*

Received 4 September 2022; accepted 11 November 2022
Available online 6 March 2023

KEYWORDS
Astigmatism;
Asymmetric bow-tie;
ICRS;
Intracorneal ring;
Keratoconus;
Refractive surgery;
Snowman phenotype

Summary
Objective. — To evaluate refractive, aberrometric, topographic, and topometric outcomes of asymmetric intracorneal ring segment (ICRS) implantation in snowman phenotype (asymmetric bow-tie) keratoconus.
Methods. — This retrospective, interventional study included eyes with snowman phenotype keratoconus. Two asymmetric ICRSs (Keraring AS) were implanted after femtosecond laser-assisted tunnel formation. Visual, refractive, aberrometric, topographic, and topometric changes after asymmetric ICRS implantation were evaluated with a mean follow-up of 11 months (6—24 months).
Main results. — Seventy-one eyes were analyzed in the study. Keraring AS implantation corrected refractive errors significantly. The mean spherical error decreased from -5.06 ± 4.23 D to -1.62 ± 3.45 D ($P = 0.001$), and the mean cylindrical error decreased from -5.43 ± 2.48 D to -2.44 ± 1.49 D ($P = 0.001$). Uncorrected distance visual acuity improved from 0.98 ± 0.80 to 0.46 ± 0.46 Log MAR ($P = 0.001$), and corrected distance visual acuity improved from 0.58 ± 0.56 to 0.17 ± 0.39 Log MAR ($P = 0.001$). Keratometry (K) maximum, K1, K2, K mean, astigmatism, and corneal asphericity (Q-value) showed a significant decrease ($P = 0.001$). Vertical coma aberration decreased significantly from -3.31 ± 2.12 µm to -2.56 ± 1.94 µm ($P = 0.001$). All topometric indices of corneal irregularities were significantly reduced postoperatively ($P = 0.001$).

Abbreviations: ICRS, Intracorneal ring segment.

* Corresponding author. Acibadem, Almondhill Sitesi, B15 Blok, D 8, Uskudar, Istanbul 34660, Turkey.
E-mail address: drbelmakayhan@gmail.com (B. Kayhan).

https://doi.org/10.1016/j.jfo.2022.11.012

Conclusions. — Keraring AS implantation in snowman phenotype keratoconus demonstrated good efficacy and safety. Clinical, topographic, topometric, and aberrometric parameters improved significantly after Keraring AS implantation.

MOTS CLÉS
Anneau intracornéen ;
Astigmatisme ;
Chirurgie réfractive ;
Kératocône ;
Nœud papillon asymétrique ;
Phénotype bonhomme de neige ;
SAIC

Résumé

Objectif. — Évaluer les résultats réfractifs, aberrométriques, topographiques et topométriques de l'implantation d'un segment d'anneau intracornéen (SAIC) asymétrique dans le kératocône de phénotype bonhomme de neige (nœud papillon asymétrique).

Méthodes. — Cette étude interventionnelle rétrospective a inclus des yeux atteints de kératocône de phénotype bonhomme de neige. Deux SAIC asymétriques (Keraring AS) ont été implantés après la formation d'un tunnel assisté par laser femtoseconde. Les changements visuels, réfractifs, aberrométriques, topographiques et topométriques après l'implantation asymétrique de SAIC ont été évalués avec un suivi moyen de 11 mois (6—24 mois).

Principaux résultats. — Soixante et onze yeux ont été analysés dans l'étude. L'implantation de Keraring AS a corrigé de manière significative les erreurs de réfraction. L'erreur sphérique moyenne a diminué de $-5{,}06 \pm 4{,}23$ D à $-1{,}62 \pm 3{,}45$ D ($p = 0{,}001$) et l'erreur cylindrique moyenne a diminué de $-5{,}43 \pm 2{,}48$ D à $-2{,}44 \pm 1{,}49$ D ($p = 0{,}001$). L'acuité visuelle de loin non corrigée est passée de $0{,}98 \pm 0{,}80$ à $0{,}46 \pm 0{,}46$ Log MAR ($p = 0{,}001$) et l'acuité visuelle de loin corrigée est passée de $0{,}58 \pm 0{,}56$ à $0{,}17 \pm 0{,}39$ Log MAR ($p = 0{,}001$). La kératométrie (K) maximale, K1, K2, K moyenne, l'astigmatisme et l'asphéricité cornéenne (valeur Q) ont montré une diminution significative ($p = 0{,}001$). L'aberration verticale du coma a diminué de manière significative de $-3{,}31 \pm 2{,}12$ µm à $-2{,}56 \pm 1{,}94$ µm ($p = 0{,}001$). Tous les indices topométriques des irrégularités cornéennes ont été significativement réduits après l'opération ($p = 0{,}001$).

Conclusions. — L'implantation de Keraring AS dans le kératocône de phénotype bonhomme de neige a démontré une bonne efficacité et une bonne innocuité. Les paramètres cliniques, topographiques, topométriques et aberrométriques se sont significativement améliorés après l'implantation de Keraring AS.

Introduction

Keratoconus is a progressive, non-inflammatory disease, resulting in a corneal cone with abnormal thinning and steepening. It causes myopia and irregular astigmatism that cannot be corrected with glasses in moderate and severe cases. The corneal cone can be central, paracentral or pericentral. The topographical abnormality in keratoconus shows different patterns. Fernandez-Vega and Alfonso described asymmetrical types of keratoconus in their latest classification [1]. Snowman phenotype (asymmetric bow-tie) is one of the asymmetrical phenotypes with astigmatic lobes of different size and perpendicular axes of topography and coma.

Intracorneal ring segments (ICRSs) regularize corneal geometry in keratoconus by adding thickness to the periphery and thus, flattening the central cornea [2,3]. In asymmetric patterns, some parts of the cornea need more flattening, compared to other parts. Therefore, new models with progressive thickness have been designed to customize the corneal effect in asymmetric keratoconus phenotypes. These models have two types with implantation zones of 5 or 6 mm. Their arc-lengths are 160°. The asymmetric segment thickens from one end to the other by 100 µm. Two types can be found in the markets, with thicknesses of 150/250 µm and 200/300 µm.

The study aimed to evaluate refractive, aberrometric, topographic, and topometric outcomes and safety of asymmetric ICRS implantation (Keraring AS) in snowman phenotype keratoconus.

Materials and methods

This retrospective, interventional study included eyes with snowman phenotype keratoconus that underwent Keraring AS (Mediphacos Ltd, Minas Gerais, Brazil) implantation. The study was carried out according to the principles of the Declaration of Helsinki. Informed consent forms were signed and approved by all participants.

The diagnosis of snowman phenotype keratoconus was based to the description by Fernandez-Vega/Alfonso [1]. Eyes whose visual acuity did not reach a satisfactory level by the patient with glasses and contact lenses were included in the study. Other eligibility criteria for the study eyes are Amsler-Krumeich stage 1—3 keratoconus, the minimal corneal thickness of 400 µm, and a clear central cornea. Exclusion criteria were history of herpes keratitis, glaucoma, uveitis, or any intraocular surgery; the presence of any retinal or neuro-ophthalmic disease; severe atopy, autoimmune or connective tissue diseases. The eyes with previous crosslinking history or any other corneal intervention were not included in the study.

Visual acuity was determined as uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA). Biomicroscopic and fundus examinations with intraocular pressure measurements were done preoperatively. Corneal tomography was performed by using Allegro Oculyzer II (WaveLight, Alcon). Keratometry (K) readings of K1, K2, K mean (3 mm), astigmatism and corneal asphericity (Q-value for 8 mm) were measured in anterior and posterior cornea. K maximum (max) value (8 mm), Z (1,3) and Z (−1,3) coma aberrations (for 6.0-mm pupil diameter) were obtained from anterior corneal measurements. Topometric indices of corneal irregularity were also recorded as index of surface variance (ISV), index of vertical asymmetry (IVA), keratoconus index (KI), central keratoconus index (CKI), index of height asymmetry (IHA), and index of height decentration (IHD) values. All measurements and examinations were repeated in every follow-up visit.

Surgery

All procedures were performed under the topical anesthesia. Corneal axes of 0 and 180° were determined by marking in upright position. An intralase femtosecond laser (IntraLase Corp., Irvine, CA, USA) with 150 kHz was used for the tunnel formation. The inner diameter was set to 4.6 mm and the outer diameter to 5.8 mm in tunnels to keep the segment ends at a sufficient distance from each other. The tunnel depth was arranged in 75% of minimum corneal thickness. The incision was placed on the steep axis. After the tunnel formation, two Keraring AS ICRSs were inserted symmetrically. When the steepest K values between two lobes in the central 3 mm optical zone was less than 5 D, two Keraring ASs of 150/250 µm were preferred for implantation. When the difference was 5 D or more, two Keraring ASs of 200/300 µm were implanted (Fig. 1). Moxifloxacin 0.5% (Vigamox, Alcon, Fort Worth, TX, USA) and dexamethasone 0.1% (Maxidex, Alcon, Puurs, Belgium), four times a day for 2 weeks and preservative-free artificial teardrop (Artelac Advanced, Bausch Lomb, NY, USA) four times a day for 1 month were used for postoperative treatment. The follow-up visits were carried out in 1st day, in 1st week, 1st, 6th, 3rd months, and 1st year after the operation.

Statistical analysis

The statistical analysis was performed by using Number Cruncher Statistical System (NCSS, 2007) program. Shapiro-Wilk test was used for the evaluation of the quantitative data compatibility to normal distribution. Dependent Samples t-test for normally distributed variables and Wilcoxon Signed Ranks test for non-normally distributed variables were used to analyze differences in comparison of results before and after surgery. A P-value < 0.05 were accepted as a statistical significance.

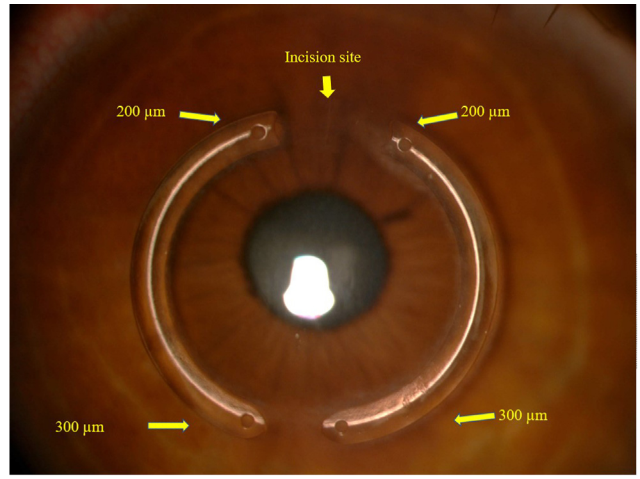


Figure 1. Slit-lamp appearance of Keraring AS implantations in snowman phenotype of keratoconus. Two Keraring AS segments of 160-degree arc length and 200/300 µm thickness were implanted symmetrically.

Results

Seventy-one eyes with snowman phenotype keratoconus were evaluated in the study. Both eyes of twenty patients and one eye of thirty-one patients comprised the study data. The mean age was 28.15 ± 7.69 years (ranging between 18 and 47 years). Forty patients were male (78.4%). The mean follow-up time was 11.2 months (ranging from 6 m to 24 m).

Keraring AS implantation resulted in significant increases in UDVA and CDVA (Fig. 2A and B). UDVA increased from 0.98 ± 0.80 to 0.46 ± 0.46 Log MAR (P = 0.001) and CDVA increased from 0.58 ± 0.56 to 0.17 ± 0.39 Log MAR (P = 0.001). Thirty-five eyes (49.2%) gained three or more lines of CDVA, thirteen eyes (18.3%) gained two lines, fifteen eyes (21.1%) gained one line (Fig. 2C). Eight eyes (11.2%) didn't demonstrate any change and no eyes showed line loss (Fig. 2C).

Refractive errors were significantly corrected after Keraring AS implantation. The mean spherical error improved from −5.06 ± 4.23 D to −1.62 ± 3.45 D (P = 0.001) and the mean cylindrical error from −5.43 ± 2.48 D to −2.44 ± 1.49 D (P = 0.001). The mean refractive spherical equivalent (MRSE) reduced from −7.78 ± 4.19 D to −2.84 ± 3.37 D (P = 0.001) (Fig. 2D).

Topographic values obtained from the anterior cornea revealed statistically significant decreases after the surgery (P = 0.001) (Table 1). K max, K1, K2, K mean, astigmatism, and Q-value decreased significantly. The analysis of K1, K2, and astigmatism from the posterior cornea yielded significant decreases (Table 2). K mean and Q-value from the posterior cornea didn't change significantly after implantations (P = 0.100 and P = 0.058) (Table 2).

Vertical coma [Z (−1,3)] decreased significantly from −3.31 ± 2.12 µm to −2.56 ± 1.94 µm (P = 0.001) (Table 3).

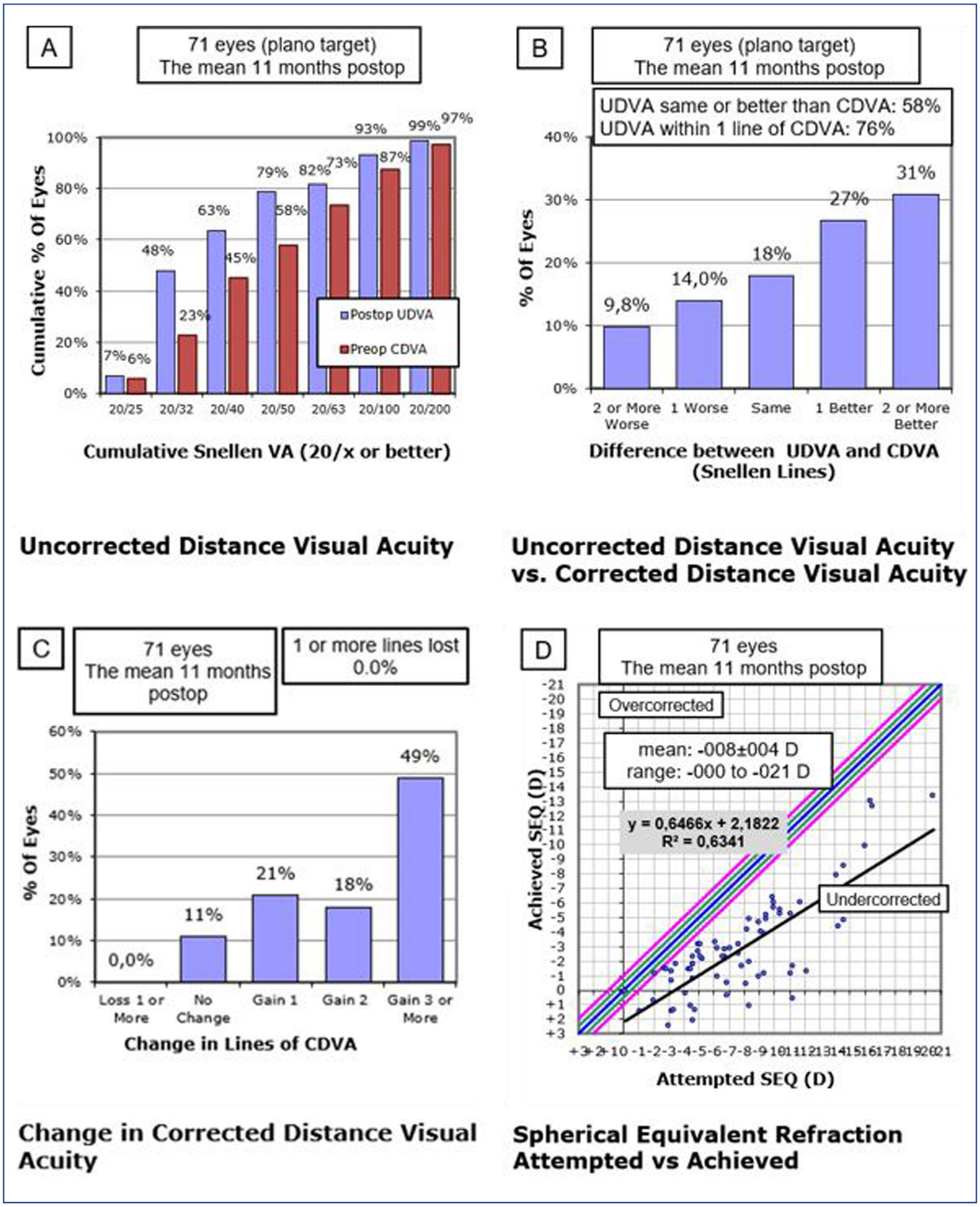


Figure 2. The graphs of visual and refractive outcomes after the implantations of two Keraring AS segments for snowman phenotype keratoconus. UDVA: uncorrected distance visual acuity; CDVA: corrected distance visual acuity; D: diopters.

Horizontal coma [Z (1,3)] changed from -0.02 ± 1.23 μm to 0.08 ± 1.19 μm and the change was statistically insignificant ($P = 0.291$) (Table 3).

All topometric indices demonstrated significant reductions postoperatively ($P = 0.001$) (Table 3).

The increase in the thinnest pachymetry measurements was 1.54 ± 2.61 μ and didn't show a statistical significance ($P = 0.075$).

No complications were observed during and after operations.

Discussion

This study revealed significant improvements in visual, refractive, aberrometric, topographic, and topometric

Table 1 Keratometric values and Q-value measurements from the anterior cornea, pre- and postoperatively.

	Preop.	Postop.	Difference	*P*
K max				
Mean ± SD	58.83 ± 5.97	52.59 ± 5.02	−6.24 ± 4.17	[b]**0.001****
(Min—max)	(48.9—79.7)	(44—69.6)		
K1				
Mean ± SD	47.63 ± 3.46	44.37 ± 3.01	−3.26 ± 2.23	[b]**0.001****
(Min—max)	(41.4—56)	(38.4—52)		
K2				
Mean ± SD	51.8 ± 3.73	46.53 ± 2.97	−5.27 ± 2.77	[b]**0.001****
(Min—max)	(44.9—63.7)	(39.9—55.6)		
K mean				
Mean ± SD	49.6 ± 3.43	45.41 ± 2.91	−4.20 ± 2.38	[b]**0.001****
(Min—max)	(43.7—59.1)	(39.1—52.3)		
Corneal astigmatism				
Mean ± SD	−3.79 ± 2.72	−1.59 ± 2.05	2.20 ± 2.17	[b]**0.001****
(Min—max)	(−11—3.1)	(−6.4—3.7)		
Q-value				
Mean ± SD	−1.04 ± 1.12	−0.37 ± 0.38	0.55 ± 1.15	[a]**0.001****
(Min—max)	(−2.1—0.51)	(−1.3—0.5)		

[a] Wilcoxon Signed Ranks Test.
[b] Paired Samples Test.
** $P < 0.01$.

Table 2 Keratometric values and Q-value measurements from the posterior cornea, pre- and postoperatively.

	Preop.	Postop.	Difference	*P*
K1				
Mean ± SD	−7.07 ± 0.71	−7.22 ± 0.73	−0.15 ± 0.32	[a]**0.001****
(Min—max)	(−8.9—−5.4)	(−9.4—−5.8)		
K2				
Mean ± SD	−7.95 ± 0.74	−7.7 ± 0.72	0.26 ± 0.33	[a]**0.001****
(Min—max)	(−10.2—−6.4)	(−10.1—−6.1)		
K mean				
Mean ± SD	−7.49 ± 0.69	−7.44 ± 0.72	0.05 ± 0.25	[a]**0.100**
(Min—max)	(−9.5—−5.9)	(−9.7—−6)		
Corneal astigmatism				
Mean ± SD	0.83 ± 0.52	0.21 ± 0.52	−0.62 ± 0.59	[a]**0.001****
(Min—max)	(−1—2.5)	(−0.8—1.4)		
Q-value				
Mean ± SD	−1.1 ± 0.42	−1.21 ± 0.67	−0.11 ± 0.48	[a]**0.058**
(Min—max)	(−2.4—−0.1)	(−3.9—−0.1)		

[a] Paired Samples Test.
** $P < 0.01$.

outcomes after asymmetric ICRS implantations in snowman phenotype keratoconus. The current study demonstrated that Keraring AS implantation significantly corrected both spherical and cylindrical refractive errors. The mean spherical error decreased from −5.06 ± 4.23 D to −1.62 ± 3.45 D and the mean cylindrical error decreased from −5.43 ± 2.48 D to −2.44 ± 1.49 D. Keraring AS implantation yielded approximately 3 D correction in the cylindrical error and 5 D correction in the MRSE. There are very few studies evaluating Keraring AS outcomes in snowman phenotype keratoconus [4—6]. Previous studies stated 1.63 D, 3.12 D, and 3.16 D of cylindrical correction and 1.52 D, 3.59 D, and 3.18 D of MRSE correction in snowman phenotype [4—6]. Another study reported a reduction of 1.81 D in cylindrical error and of 2.54 D in MRSE, but this study stated the refractive outcomes without separating the outcomes in the subgroups of croissant, duck, and snowman phenotypes [7].

UDVA and CDVA also improved significantly after Keraring AS implantation in snowman phenotype keratoconus. The study demonstrated both a 0.52 Log MAR improvement in

Table 3 Changes in coma aberrations from the anterior cornea and topometric indices after Keraring AS implantations.

	Preop.	Postop.	Difference	*P*
Vertical coma [Z (−1,3)]				
Mean ± SD	−3.31 ± 2.12	−2.56 ± 1.94	0.74 ± 0.91	[b]***0.001****
(Min—max)	(−15.5—0.1)	(−12.1—1.2)		
Horizontal coma [Z (1,3)]				
Mean ± SD	−0.02 ± 1.23	0.08 ± 1.19	0.10 ± 0.79	[b]***0.291***
(Min—max)	(−2.8—2.3)	(−2.8—3.1)		
ISV				
Mean ± SD	95.32 ± 27.31	68.25 ± 24.41	27.07 ± 13.51	[b]***0.001****
(Min—max)	(44—198)	(20—153)		
IVA				
Mean ± SD	0.94 ± 0.35	0.74 ± 0.29	−0.20 ± 0.21	[b]***0.001****
(Min—max)	(0.3—2.1)	(0.2—1.6)		
KI				
Mean ± SD	1.26 ± 0.12	1.14 ± 0.11	−0.12 ± 0.07	[b]***0.001****
(Min—max)	(1—1.9)	(1—1.6)		
CKI				
Mean ± SD	1.09 ± 0.05	1.06 ± 0.05	−0.02 ± 0.03	[a]***0.001****
(Min—max)	(1—1.2)	(1—1.2)		
IHA				
Mean ± SD	42.89 ± 32.23	29.66 ± 20.97	13.23 ± 30.93	[a]***0.001****
(Min—max)	(0.2—156)	(0.2—90.6)		
IHD				
Mean ± SD	0.14 ± 0.06	0.1 ± 0.13	−0.04 ± 0.13	[a]***0.001****
(Min—max)	(0—0.4)	(0—1.2)		

[a] Wilcoxon Signed Ranks Test.
[b] Paired Samples Test.
** $P < 0.01$.

UDVA and 0.41 Log MAR improvement in CDVA. Sixty-three eyes (88.6%) gained at least one line of CDVA. Baptista et al. reported an average UDVA gain of 0.15 (decimal) and CDVA gain of 0.19 (decimal) in their fourteen snowman phenotype case-series [4]. Coskunseven et al. found an UCVA and CDVA improvement of 0.60 and 0.19 Log MAR, respectively, in five cases of the snowman subgroup [7]. Prisant's study including 29 eyes with snowman phenotype reported 0.36 Log MAR increase in UDVA, and merely 0.05 Log MAR increase in CDVA [5]. Similar to the previous study, Barugel et al. documented improvements of 0.28 Log MAR in UDVA and 0.08 Log MAR in CDVA in a series of seventeen cases [6]. The current study showed similar results in correcting the cylindrical error compared to previous studies, but the MRSE correction was about twice that of the others. In addition, although the results in UDVA were similar, the increase in CDVA was significantly higher in the present study. Compared to other Keraring AS studies in the snowman phenotype, the number of cases in our study group was significantly higher.

All keratometric values of the anterior cornea revealed statistically significant improvements (Fig. 3). The highest difference was 6.24 D in K max value, followed by K2 with 5.27 D and K1 with 3.26 D. The change in K mean was 4.20 D. Consistent with the results of our study, Barugel et al. stated 6.09 D reduction in K max, 5.67 D in K2, and 2.80 D in K1 after Keraring AS implantation for snowman phenotype keratoconus [6]. K mean change in the same study was 4.09 D that is very close to our data of K mean. Prisant et al. reported a 5 D decrease in K max value in eyes with two asymmetric ring implants [5]. In another series of 14 cases, a decrease of K max was 2.08 D [4]. Fernandez-Vega-Cueto et al. reported a maximum decrease of 0.95 D in K1 and 1.43 D in K2 in their study comparing the implantation axis of a single symmetrical 150° arc-length Ferrara ring in two separate axes [8]. The improvements of keratometric values in the current study were much higher than both other asymmetric ICRS and symmetric, standard ICRS implantations in snowman phenotype keratoconus.

Higher order aberrations, particularly coma aberrations, are main indicators for the diagnosis of keratoconus [9,10]. Coma aberration was also found higher in asymmetric bow-tie pattern corneal topography, compared to round, oval, symmetric bow-tie, and irregular patterns in normal corneas [11]. Decreased visual acuity and quality are related to the increased higher order aberration in eyes with keratoconus or keratoconus suspect [12]. Coma values has an independent impact on visual acuity in keratoconus [13]. Our study showed a significant decrease in vertical coma, values from −3.31 ± 2.12 to −2.56 ± 1.94, and an insignificant change of horizontal coma, with a difference of 0.10 ± 0.79. The improvement in coma corresponds to high increments of the visual acuity in the current study. Coma values didn't

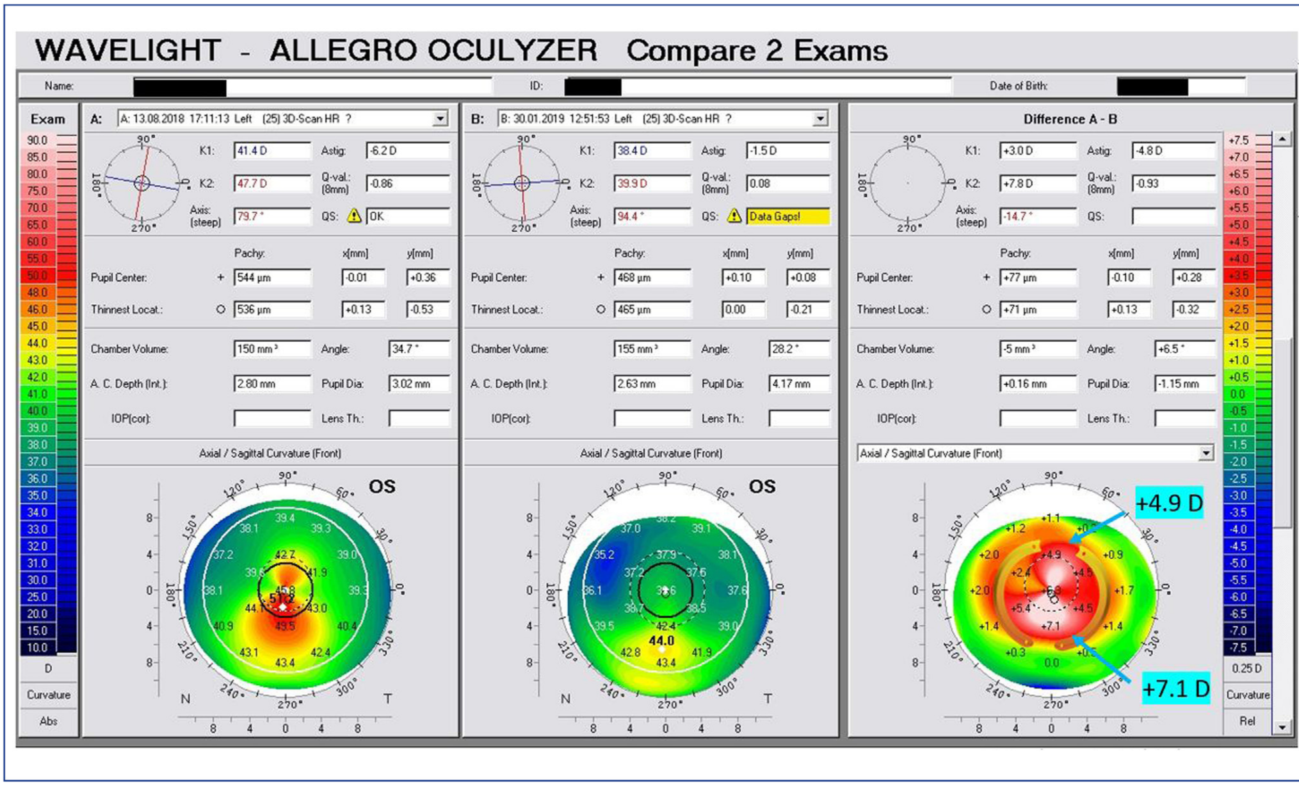


Figure 3. Change in corneal topography after Keraring AS implantation. On the left, the corneal topography before Keraring AS implantation for snowman phenotype keratoconus; in the middle, the corneal topography after Keraring AS implantation at the same eye; on the right, the difference map showing topographical correction with 4.9 D in the upper half and 7.1 D in the lower half of the cornea.

change statistically in the study done by Barugel et al., but they evaluated total coma instead of separate vertical and horizontal components [6].

Q-value was another parameter related to visual acuity and quality in the study. A normal cornea has about −0.26 of Q-value. In keratoconus, the cornea becomes steeper and more prolate, inducing higher Q-values than in normal corneas [14—16]. The preoperative Q-value was −1.04. It decreased to −0.37 postoperatively, demonstrating flattening of the cornea close to the physiological asphericity level. The improvement was compatible with visual acuity gain and keratometry changes.

Topometric indices obtained in Pentacam and Oculyzer devices give data of corneal irregularity. A study suggests ISV and IHD to determine the progression of keratoconus after the surgery. [17]. IVA and IHA compare two parts of the cornea in the vertical plane. A decrease in IVA and IHA points out an improvement of the asymmetry. The indices of KI and CKI are parameters about keratoconus grade [18]. All topometric indices showed a significant decrease in the present study. These outcomes highlight a remarkable improvement in vertical asymmetry, decentration, and keratoconus severity after Keraring AS implantation. To our knowledge, apart from our study, only Barugel et al. investigated the topometric indices after Keraring AS in snowman phenotype keratoconus [6]. They found a statistically significant decrease in ISV, KI, CKI. Although they also reported reductions in IVA, IHA, and IHD, these were statistically insignificant.

Keraring AS is an ICRS with variable thickness and uniform base width of 60 µm. Two studies reported outcomes about another asymmetric ICRS which has progressive base width accompanying progressive thickness [19,20]. The authors also stated good outcomes of refractive and topographic correction with that type of asymmetric ICRS [19,20].

The limitation of the study is that the asymmetric ICRS results were not compared with the results of standard ring implants of the same phenotype. Another limitation is its retrospective nature.

Conclusion

Keraring AS implantation in snowman phenotype keratoconus demonstrated good efficacy and safety. Clinical, topometric, topometric, and aberrometric parameters improved significantly after Keraring AS implantation.

Authors' note

All authors declare that they meet the current ICMJE criteria for authorship.

Authors' Contributions

EC contributed to the conception, design and writing of the study, acquisition, analysis and interpretation of the data.

BK contributed the conception, design and writing of the study, acquisition, analysis and interpretation of the data. All authors made the critical revision of the article, read and approved the submitted manuscript.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Acknowledgments

This study was partially presented at the Annual meeting of American Society of Cataract and Refractive Surgeons in 2022.

Disclosure of interest

B.K. declares that he has no competing interest.

E.C. Consultant in Mediphacos Ltd.

References

[1] Alfonso JF, Lisa C, Fernández-Vega L, Poo-López A, Madrid-Costa D. Clasificación del queratocono basada en fenotipos clínicos. Influencia del astigmatismo congénito en la morfología del queratocono. In: Del Buey Sayas MA, Peris Martínez C, editors. Biomecánica y arquitectura corneal. Barcelona, España: Elsevier: Vol Monografias SECOIR; 2014, p. 165—84.

[2] Colin J, Cochener B, Savary G, Malet F. Correcting keratoconus with intracorneal rings. J Cataract Refract Surg 2000;26:1117—22.

[3] Coskunseven E, Kymionis GD, Tsiklis NS, Atun S, Arslan E, Jankov MR, et al. One-year results of intrastromal corneal ring segment implantation (KeraRing) using femtosecond laser in patients with keratoconus. Am J Ophthalmol 2008;145:775—9.

[4] Baptista PM, Marques JH, Neves MM, Gomes M, Oliveira L. Asymmetric thickness intracorneal ring segments for keratoconus. Clin Ophthalmol 2020;14:4415—21.

[5] Prisant O, Pottier E, Guedj T, Hoang Xuan T. Clinical outcomes of an asymmetric model of intrastromal corneal ring segments for the correction of keratoconus. Cornea 2020;39:155—60.

[6] Barugel R, David C, Kallel S, Borderie M, Cuyaubère R, Goemaere I, et al. Comparative study of asymmetric versus non-asymmetric intrastromal corneal ring segments for the management of keratoconus. J Refract Surg 2021;37:552—61.

[7] Coşkunseven E, Ambrósio Jr R, Smorádková A, Sánchez León F, Sahin O, Kavadarli I, et al. Visual, refractive and topographic outcomes of progressive thickness intrastromal corneal ring segments for keratoconic eyes. Int Ophthalmol 2020;40:2835—44.

[8] Fernández-Vega-Cueto L, Lisa C, Alfonso-Bartolozzi B, Madrid-Costa D, Alfonso JF. Intrastromal corneal ring segment implantation in paracentral keratoconus with perpendicular topographic astigmatism and comatic axis. Eur J Ophthalmol 2021;31:1540—5.

[9] Castro-Luna G, Pérez-Rueda A. A predictive model for early diagnosis of keratoconus. BMC Ophthalmol 2020;20:263.

[10] Naderan M, Jahanrad A, Farjadnia M. Ocular, corneal, and internal aberrations in eyes with keratoconus, forme fruste keratoconus, and healthy eyes. Int Ophthalmol 2018;38:1565—73.

[11] Mirzajani A, Aghataheri S, Ghoreishi M, Jafarzadepour E, Mohammadinia M. Evaluation of corneal higher order aberrations in normal topographic patterns. J Curr Ophthalmol 2016;28:75—80.

[12] Shneor E, Piñero DP, Doron R. Contrast sensitivity and higher-order aberrations in keratoconus subjects. Sci Rep 2021;11:12971.

[13] Wisse RP, Gadiot S, Soeters N, Godefrooij DA, Imhof SM, van der Lelij A. Higher-order aberrations 1 year after corneal collagen crosslinking for keratoconus and their independent effect on visual acuity. J Cataract Refract Surg 2016;42:1046—52.

[14] Utine CA, Özizmirliler D, Kayabaşı M, Günenç Ü. The number of intracorneal ring segments in asymmetric and central cones. Eye Vis (Lond) 2021;8:10.

[15] Utine CA, Ayhan Z, Durmaz Engin C. Effect of intracorneal ring segment implantation on corneal asphericity. Int J Ophthalmol 2018;11:1303—7.

[16] Sedaghat MR, Momeni-Moghaddam H, Piñero 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.

[17] Kanellopoulos AJ, Asimellis G. Revisiting keratoconus diagnosis and progression classification based on evaluation of corneal asymmetry indices, derived from Scheimpflug imaging in keratoconic and suspect cases. Clin Ophthalmol 2013;7:1539—48.

[18] Doctor K, Vunnava KP, Shroff R, Kaweri L, Lalgudi VG, Gupta K, et al. Simplifying and understanding various topographic indices for keratoconus using Scheimpflug based topographers. Indian J Ophthalmol 2020;68:2732—43.

[19] Cuiña Sardiña R, Arango A, Alfonso JF, Álvarez de Toledo J, Piñero DP. Clinical evaluation of the effectiveness of asymmetric intracorneal ring with variable thickness and width for the management of keratoconus. J Cataract Refract Surg 2021;47:722—30.

[20] Kammoun H, Piñero DP, Álvarez de Toledo J, Barraquer RI, García de Oteyza G. Clinical outcomes of femtosecond laser-assisted implantation of asymmetric icrs in keratoconus with no coincidence of topographic and comatic axes. J Refract Surg 2021;37:693—9.