Special Focus, Cornea, Original Article

Clinical, tomographic, and topometric outcomes of progressive thickness intracorneal ring segment implantations in duck-type keratoconus

Efekan Coskunseven[1,2], Belma Kayhan[1,3]

Purpose: To evaluate the visual, refractive, tomographic, and topometric outcomes of progressive thickness intracorneal ring segment (PT-ICRS) implantation in duck-type keratoconus. **Methods:** This retrospective study included eyes with oval (duck-type) keratoconus treated with PT-ICRS implantation. After the femtosecond laser tunnel creation, one PT-ICRS (Keraring AS 5 with 160° arc length) was implanted along the ectatic, inferior half of the cornea. Data of uncorrected and corrected distance visual acuity (UDVA and CDVA), refraction, asphericity (Q value), and keratometry (K) were compared pre- and postoperatively. Additionally, changes in the topometric indices of corneal irregularity were also evaluated after PT-ICRS implantation. **Results:** Thirty-one eyes of 30 patients were included in the study with a mean follow-up time of 9.06 months (ranging between 6 and 18 months). UDVA improved from 0.85 ± 0.36 to 0.27 ± 0.14 logMAR (P = 0.001), and CDVA improved from 0.37 ± 0.22 to 0.13 ± 0.11 logMAR (P = 0.001). The mean spherical error decreased from −3.66 ± 2.60 to −1.60 ± 1.42 D (P = 0.001), and the mean cylindrical error decreased from −4.91 ± 2.65 to − 1.41 ± 1.31 D (P = 0.001). All topographic parameters measured from the anterior cornea demonstrated statistically significant improvements after PT-ICRS implantation (P = 0.001). K mean, K maximum, corneal astigmatism, and Q value showed a significant decrease. Besides the index of height asymmetry, all topometric indices were significantly reduced after PT-ICRS implantation. There were no loss of lines and no complications. **Conclusion:** PT-ICRS implantation in duck-type keratoconus is an effective and safe treatment. This intervention improves the visual acuity, refractive error, topographical, and topometric parameters significantly by decreasing both eccentricity and steepness of the cone.

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Intracorneal ring segment (ICRS) is inserted within the corneal stroma to modify the geometry and refractive power of the cornea. Initially, ICRS was developed for the correction of myopia.[1-3] Afterward, ICRS implantation has proven to be an effective and safe treatment for the correction of irregular astigmatism and myopia in keratoconus.[4-7] The ICRS effect is directly proportional to the ICRS thickness and inversely proportional to the optical zone of ICRS. Standard, stable ICRSs have been designed with uniform thickness. In a standard ICRS, the effect of the ring is almost equal along the ring track. Keratoconus shows different topographical patterns in different corneas. In asymmetric patterns of corneal ectasia, some parts of the cornea require more correction while some require less. Like other refractive procedures, the customized correction will increase both topographical and refractive success in ICRS implantation. Recently, new asymmetric Keraring AS models (Mediphacos Ltd, Minas Gerais, Brazil) have been introduced to customize the corneal effect. Contrary to the uniformity of the thickness in standard, symmetric ICRS, asymmetric models have progressive thickness. The thicker part of this new asymmetric ICRS has more effect than the thinner part. This feature offers a progressive, tailor-made flattening effect that allows a surgeon to carefully customize corneal remodeling according to topographical needs.

The models AS 5 and AS 6 have an arc length of 160° with 5 and 6 mm optical zones, respectively. The cross section is triangular and the base width is 600 µm in both models. ICRS is the thinnest at one end (located near the incision) and gradually increases by 100 µm toward the opposite end, where it is the thickest. The thickness increase can be clockwise or counterclockwise. Two different thicknesses, 150/250 and 200/300 µm, are available in these models. Asymmetrical phenotypes according to the symmetry between the lobes of topographic astigmatism, such as snowman and duck phenotypes, are ideal for Keraring AS ICRS implantation.

In this study, we aimed to evaluate the visual, refractive, topographical outcomes, effectiveness, and safety of progressive thickness ICRS (PT-ICRS) implantation in duck-type keratoconus.

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Methods

This retrospective, interventional study included eyes with oval (duck-type) keratoconus that underwent PT-ICRS implantation. The procedures were performed by the same surgeon. The study followed the tenets of the Declaration of Helsinki. All patients signed informed consent forms before treatment.

Keratoconus severity of grades I, II, and III according to Amsler–Krumeich classification, maximum keratometry below 65 D, and minimal corneal thickness of 400 μm or more were the other parameters for inclusion. Oval (duck-type) keratoconus was determined according to the criteria of Fernandez-Vega/Alfonso classification.[8] Exclusion criteria were the presence of central corneal scarring, autoimmune or connective tissue diseases, and severe atopy. The eyes with keratoconus types other than duck type and previous crosslinking history were also excluded.

A complete ophthalmologic examination was performed preoperatively. Visual acuity was detected in decimal notation and converted to logMAR for the statistical analysis. Uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), and manifest refraction were measured preoperatively and in every postoperative examination, in addition to slit-lamp examinations and intraocular pressure measurements.

Scheimpflug images of the cornea were taken by using Allegro Oculyzer II (WaveLight, Alcon) preoperatively and in every postoperative visit. K mean (3 mm), astigmatism, and Q-value (8 mm) measurements from both anterior and posterior cornea and K maximum (max) value (8 mm) from the anterior cornea were recorded. In addition, topometric indices of corneal irregularity, that is, 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 at 8 mm zone, were also analyzed before and after PT-ICRS implantation.

ICRS planning

A single Keraring AS 5 was implanted in all cases [Fig. 1a and b]. The topographical correction was the primary aim of PT-ICRS implantation. The refractive error was not taken into consideration in planning. If there was enough corneal thickness after PT-ICRS implantation, topography-guided excimer laser and simultaneous corneal crosslinking were performed at least 1 year later. Afterward, if there was still a residual refractive error, a posterior chamber phakic intraocular lens (toric or non-toric) implantation was considered.

In the decision of Keraring ICRS model, a personal approach was applied instead of the manufacturer's nomogram [Fig. 2a]. The first step was to assess the degree of asymmetry on the cornea. The anterior cornea was divided into four quadrants by drawing two lines over steep and flat axes on the topographical map. The areas of the central 5 mm optical zone corresponding to two inferior, ectatic quadrants were evaluated. If the difference between the steepest K value in the more ectatic quadrant (the quadrant below the flat axis line in the majority of the cases) and the flattest K value in the less ectatic quadrant (the quadrant over the flat axis line in the majority of the cases) was more than 5 D, the type of keratoconus was accepted as asymmetrical and Keraring AS implantation was planned.

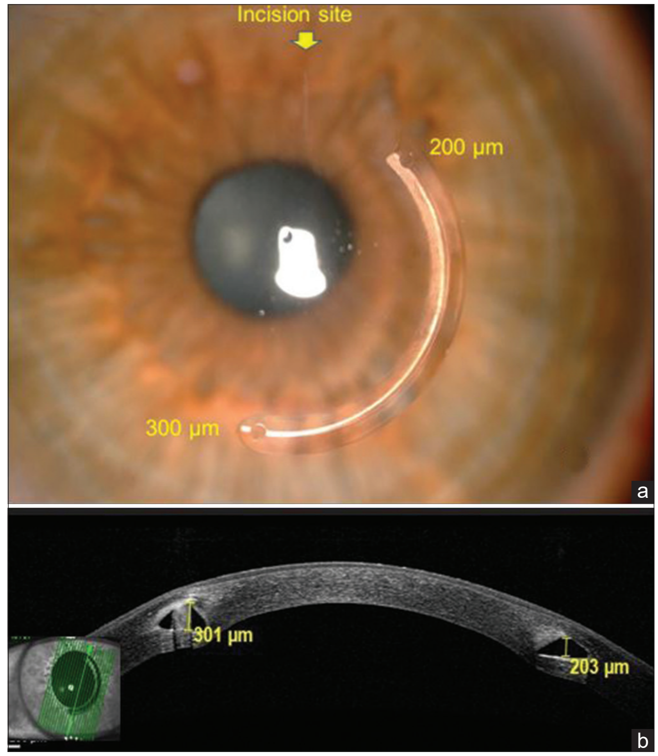

Figure 1: (a) The slit-lamp picture of Keraring AS of 200/300 μm within the cornea. (b) The anterior segment optical coherence tomography image of Keraring AS in Fig. 1a

In the determination of ICRS thickness, the line marking the steep axis was accepted as the reference line [Fig. 2b]. If the difference of the steepest K values between two hemispheres of the central 3 mm optical zone was less than 5 D, the model of 150/250 μm thickness was implanted. If the difference was 5 D or more, the model of 200/300 μm was implanted. The thicker end of the ring was directed into the steeper quadrant of the ectasia [Fig. 3].

Surgery

At the slit-lamp biomicroscope, 0° and 180° points were marked on the cornea to avoid the cyclotorsion effect on the supine position. All procedures were performed under topical anesthesia. The Purkinje reflex was marked on the anterior corneal epithelium under the operating microscope. The ring tunnels were created by using a 150 kHz IntraLase femtosecond laser (IntraLase Corp., Irvine, CA, USA). The inner and outer diameters of tunnels were 4.4. and 5.6 mm, respectively, with an entry cut length of 1.10 mm, and the tunnel depth was set as 75% of minimum corneal thickness. The tunnel incision was made 30° away from the steepest axis to prevent any extrusion. After the tunnel formation, ICRS was inserted using a forceps and positioned with a Sinskey hook. A bandage contact lens was placed and no stitches were used for the incision. Moxifloxacin and dexamethasone drop, four times a day for 2 weeks, and preservative-free artificial teardrop, four times a day for 1 month, were prescribed postoperatively. The following day, the contact lens was removed. The patients were followed on the first day, in the first week, first and third months, and first year after the operation.

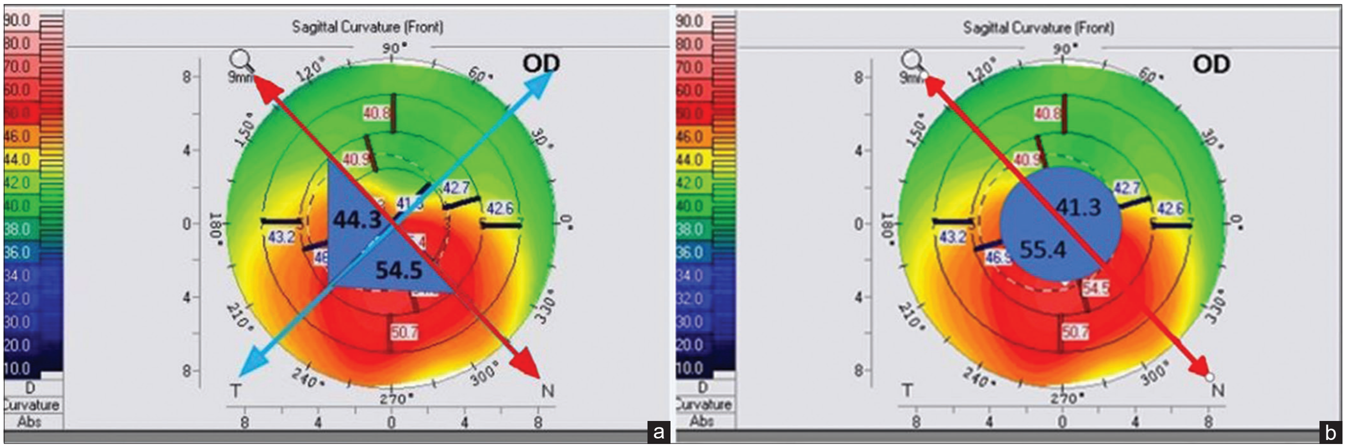

Figure 2: (a) The steep and flat axes divided the topography into four quadrants. The difference between the steepest K value in the more ectatic, inferior quadrant and the flattest K value in the less ectatic, superior quadrant in 5 mm optical zone was more than 5 D. Keraring AS implantation was planned. (b) The steep axis was accepted as the reference line. The difference in the steepest K values between two hemispheres of the central 3 mm optical zone was higher than 5 D. A Keraring AS of 200/300 μm was planned to implant

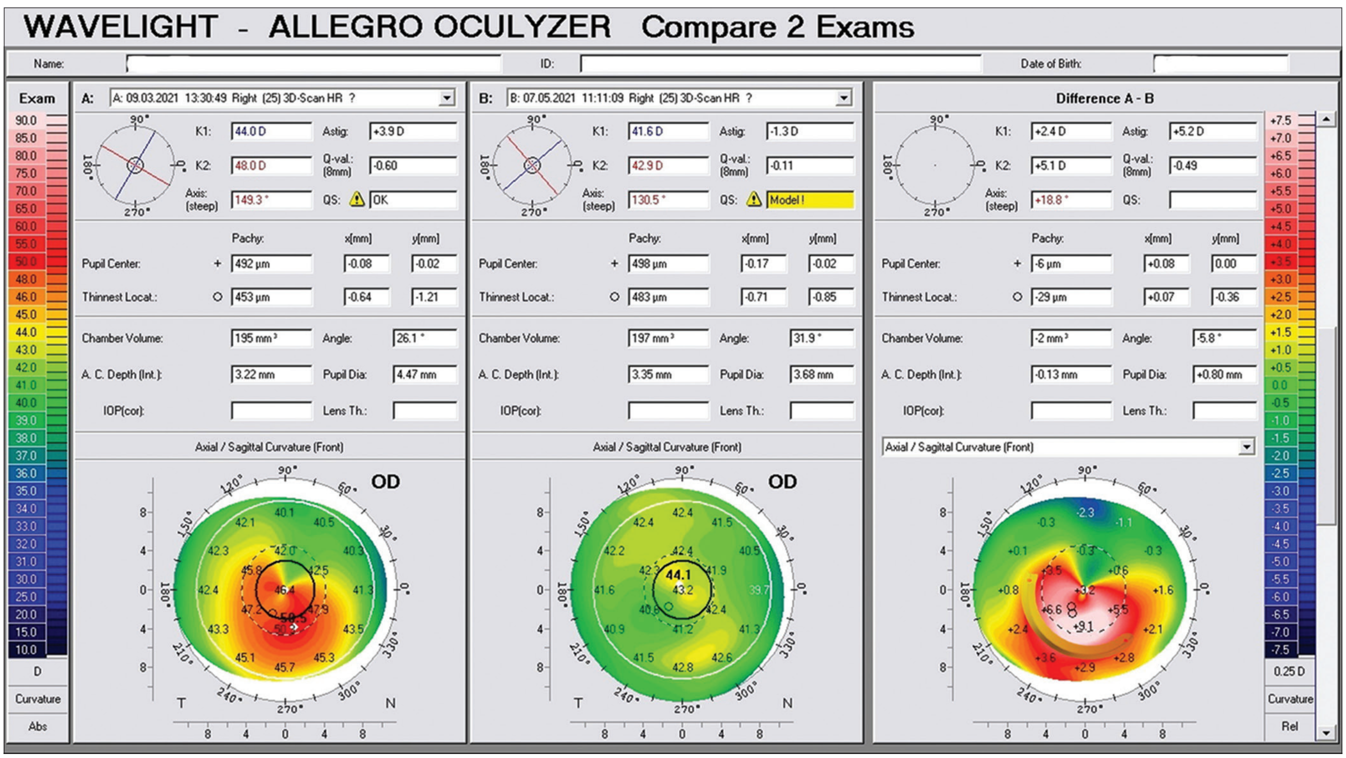

Figure 3: Topographical maps demonstrating the localization and effect of PT-ICRS. On the left, preoperative topography; in the middle, postoperative topography; on the right, the difference map with the ring diagram showing the regularizing effect of PT-ICRS. PT-ICRS = progressive thickness intracorneal ring segment

Statistical analysis

Number Cruncher Statistical System (NCSS, 2007) was used for statistical analysis and interpretation of data. Descriptive statistical methods were reported as the mean, standard deviation, median, frequency, ratio, minimum, and maximum to evaluate the study data. The compatibility of the quantitative data to normal distribution was analyzed with Shapiro–Wilk test and graphical evaluations. Dependent samples *t*-test for normally distributed variables and Wilcoxon signed-rank test for non-normally distributed variables were applied for the differences in data while comparing the results pre- and postoperatively. *P* values less than 0.05 were considered statistically significant.

Results

Thirty-one eyes of 30 patients with oval (duck-type) keratoconus were analyzed in the study. The mean age was 27.19 ± 9.41 years (ranging between 18 and 47 years). Twenty-three patients were male (76.6%). The mean follow-up time was 9.06 months (minimum 6 months and maximum 18 months).

PT-ICRS implantation corrected the refractive errors significantly. The mean spherical error decreased from −3.66 ± 2.60 D to − 1.60 ± 1.42 D (*P* = 0.001) [Fig. 4a], and the mean cylindrical error decreased from −4.91 ± 2.65 D to −1.41 ± 1.31 D (*P* = 0.001) [Fig. 4b]. Accordingly, the mean refractive spherical equivalent (MRSE) reduced from −6.19 ± 3.19 D to −2.45 ± 1.61 D (*P* = 0.001) [Fig. 4c]. UDVA and CDVA demonstrated statistically significant improvements after PT-ICRS implantation. UDVA improved from 0.85 ± 0.36 to 0.27 ± 0.14 logMAR (*P* = 0.001), and CDVA improved from 0.37 ± 0.22 to 0.13 ± 0.11 logMAR (*P* = 0.001). Fifteen eyes (48.3%) gained three or more lines of CDVA, 10 eyes (32.2%) gained two lines, and five eyes (16.1%) gained one line [Fig. 4d]. One eye (3.2%) had no change and no eyes lost lines [Fig. 4d].

All topographic parameters measured from the anterior cornea demonstrated statistically significant improvements after PT-ICRS implantation (*P* = 0.001) [Table 1]. K mean, Kmax, astigmatism, and corneal asphericity (Q value) showed a significant decrease.

In the analysis of topographic parameters from the posterior cornea, K mean and astigmatism demonstrated significant decreases [Table 1]. Q value from the posterior cornea did not show a statistically significant change (*P* = 0.065) after PT-ICRS implantations [Table 1].

Topometric indices of ISV, IVA, KI, CKI, and IHD were significantly reduced after PT-ICRS implantation [Table 2]. IHA also demonstrated a decrease of 14.06 ± 34.32 µm, but it was not statistically significant [Table 2].

The thinnest pachymetry measurements increased significantly from 456.29 ± 35.49 to 468.06 ± 37 µm postoperatively (*P* = 0.001).

No intraoperative or postoperative complications were seen.

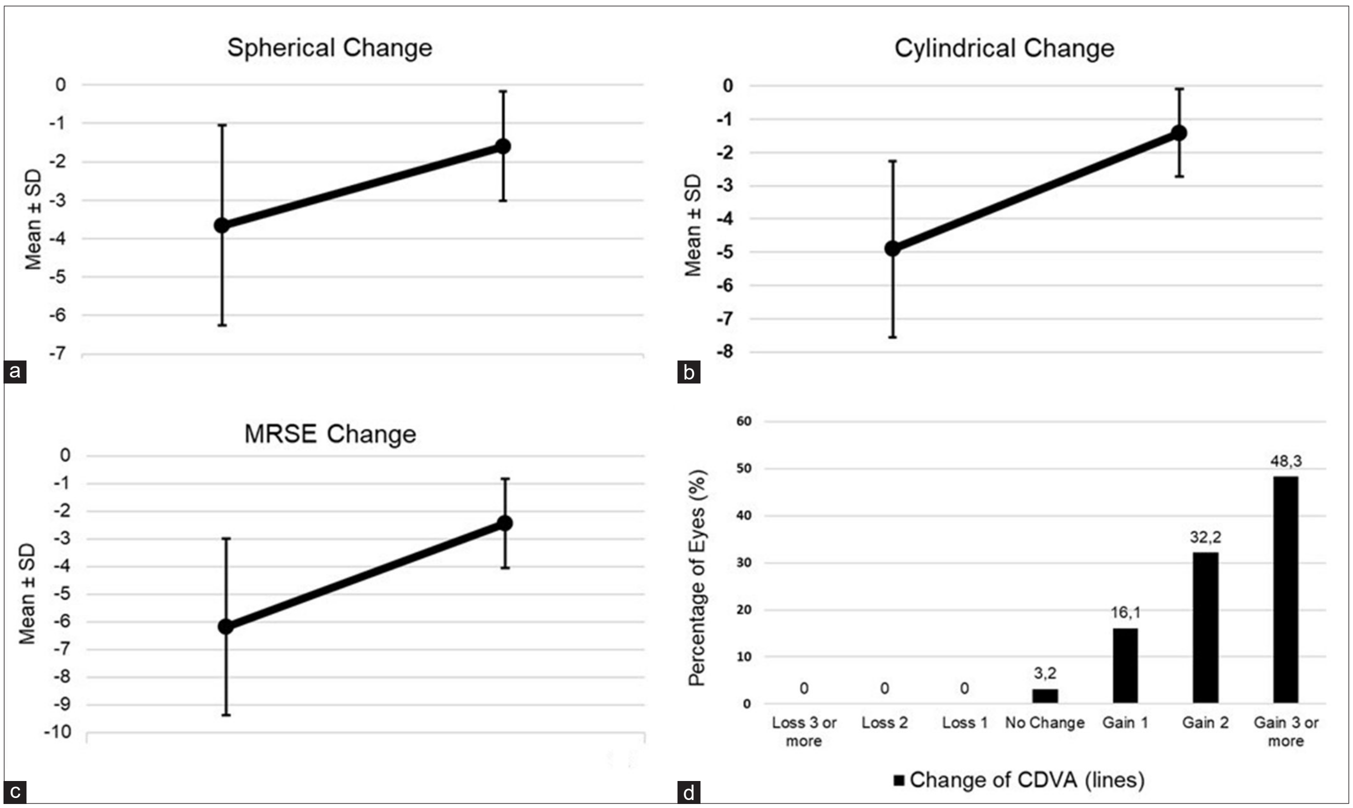

Figure 4: (a) Spherical error change; (b) cylindrical error change; (c) MRSE change; (d) change of CDVA in lines. CDVA = corrected distance visual acuity, MRSE = mean refractive spherical equivalent

Table 1: Topographical changes of the anterior and posterior cornea after PT-ICRS implantation

	Preoperative	Postoperative	*P*
Front K mean (D) (min./max.)	47.96±2.57 (43.8/53.1)	45.57±2.59 (42/52.2)	0.001**[a]
Front Kmax (D) (min./max.)	57.26±4.04 (50.5/65)	52.70±4.37 (45.2/61.6)	0.001**[a]
Front astigmatism (D) (min./max.)	−2.65±2.95 (−8/4.7)	−1.50±1.82 (−6.4/3.8)	0.001**[b]
Front Q value (min./max.)	−0.95±0.27 (−1.6/−0.5)	−0.54±0.28 (−1.1/−0.1)	0.001**[a]
Back K mean (D) (min./max.)	−7.11±0.54 (−8.4/−6.2)	−7.03±0.59 (−8.3/−6.2)	0.037*[a]
Back astigmatism (D) (min./max.)	0.55±0.60 (−1/1.3)	0.25±0.54 (−0.8/1.3)	0.001**[a]
Back Q value (min./max.)	−0.89±0.33 (−1.7/−0.3)	−0.78±0.35 (−1.4/−0.1)	0.065[b]

PT-ICRS=progressive thickness intracorneal ring segment. [a]Paired-samples *t*-test; [b]Wilcoxon signed-rank test; *$P<0.05$; **$P<0.01$

Table 2: Changes of topometric indices after PT-ICRS implantation

	Preoperative	Postoperative	*P*
ISV (min./max.)	94.87±33.74 (46/208)	69.55±27.41 (30/163)	0.001**[a]
IVA (min./max.)	1.06±0.44 (0.5/2.4)	0.81±0.35 (0.3/2)	0.001**[b]
KI (min./max.)	1.27±0.14 (1.1/1.8)	1.17±0.11 (1/1.6)	0.001**[b]
CKI (min./max.)	1.07±0.03 (1/1.1)	1.05±0.04 (1/1.1)	0.008**[a]
IHA (min./max.)	36.98±29.35 (2.8/128.1)	22.92±16.76 (0.3/67.6)	0.063[b]
IHD (min./max.)	0.15±0.07 (0.1/0.4)	0.09±0.05 (0/0.2)	0.001**[b]

ISV=index of surface variance, IVA=index of vertical asymmetry, KI=keratoconus index, CKI=central keratoconus index, IHA=index of height asymmetry, IHD=index of height decentration, PT-ICRS=progressive thickness intracorneal ring segment. [a]Paired-samples t-test; [b]Wilcoxon signed-rank test; *$P<0.05$; **$P<0.01$

Discussion

Our study demonstrated that PT-ICRS implantation improved visual, refractive, topographic, and topometric parameters significantly in duck-type keratoconus. Although many studies reported good outcomes with standard-thickness ICRS implantations,[9-11] studies about PT-ICRS are few.

In the present study, the mean UDVA and mean CDVA increases were 0.58 and 0.24 logMAR, respectively. Compared to the studies with standard ICRS in a similar type of keratoconus, our study results showed better improvements of visual acuity. Alfonso *et al*.[10] stated 0.23 logMAR increase of UDVA and 0.06 logMAR increase of CDVA after one standard Keraring ICRS implantation in asymmetric keratoconus. In a similar study done in eyes with inferior cones, a single standard ICRS (Intacs SK) implantation yielded increments of 0.43 logMAR in UDVA and 0.18 logMAR in CDVA.[12] Monteiro *et al*.[13] found mean UDVA and CDVA increments of 0.41 and 0.22 logMAR, respectively, in standard Keraring ICRS implantation. Utine *et al*.[14] implanted a single Keraring ICRS in asymmetric cones and observed improvements of 0.31 and 0.29 Snellen lines in UDVA and CDVA, respectively. In the study done by Barugel *et al*.,[15] UDVA increased by 0.44 logMAR and CDVA increased by 0.22 logMAR after implantation of a single standard Keraring ICRS in duck-type keratoconus. On the other hand, studies done with PT-ICRS reported increases in UDVA ranging from 0.34 to 0.48 logMAR and CDVA increase ranging from 0.12 to 0.19 logMAR.[15-18] The values of UDVA and CDVA improvements in the current study were slightly higher than those in studies with PT-ICRS.

To our knowledge, this is the first study evaluating corneal asphericity (Q value) in PT-ICRS implantation. A normal corneal surface has a Q value of about −0.26. Q value in a keratoconic cornea is higher and more negative than in a normal cornea because increasing steepness induces a more prolate cornea. In the present study, the average preoperative Q value of the anterior surface was − 0.95 (ranging from −1.60 to −0.50). Other studies reported similar Q values in keratoconic eyes.[14,19,20] After PT-ICRS implantation, the anterior Q value reduced to − 0.54, approaching the physiologic value. Utine *et al*.[19] reported a 0.49 change of the anterior Q value after standard ICRS implantation, but they did not define a special type of keratoconus in the study. In another study with standard ICRS in the central type keratoconus, Q value improvements ranged from 0.43 to 0. 86.[21] A study done with PT-ICRS found an improvement from −0.72 to −0.39, but this study evaluated Q value in all asymmetric types without separating duck type.[17] PT-ICRS implantation in duck-type keratoconus provided optimal corneal asphericity. Our finding was in line with the aforementioned studies.[17,19,21]

Topographic measurements related to the anterior cornea demonstrated statistically significant improvements as well. K mean and corneal astigmatism exhibited a significant decrease from both the anterior and posterior surfaces. Kmax and K mean from the anterior cornea showed a 4.56 and 2.39 D decline, respectively, in our series. When compared to standard ICRS implantations for a similar type of keratoconus, two studies reported K mean decrease of 1.22 and 1.98 D, respectively.[13,14] Another study observed 4.84 D reduction of Kmax in moderate to severe keratoconus with inferior cones.[12] Barugel *et al*.[15] evaluated the outcomes of standard Keraring ICRS and asymmetric thickness Keraring ICRS and compared the two groups. While they found K mean and Kmax decrease as 1.79 and 3.29 D, respectively, in the standard Keraring group, the K mean and Kmax decrease were 2.47 and 4.31 D, respectively, in the asymmetric Keraring group.[15] Although the magnitude of improvements was higher in the asymmetric Keraring group, the difference between groups did not show a statistical significance in the mentioned study. Other studies evaluating PT-ICRS implantation for duck-type keratoconus have reported a decrease in Kmax from 2.60 to 5.00 D, while K mean reduction was about 1.9 D.[16-18,22] In the present study, the reduction of Kmax value was similar to that found in other studies of standard ICRS and PT-ICRS implantations, but K mean reduction was better than that in standard ICRS implantations and was consistent with the PT-ICRS implantation group in the study by Barugel *et al*.[15]

In the current study, all topometric indices showed improvements after PT-ICRS implantation. The improvements were statistically significant, besides IHA. ISV reduced remarkably from 94.87 to 69.55. IHD value was 0.15 µm preoperatively and decreased to 0.09 µm postoperatively. Kanellopoulos and Asimellis stated that ISV and IHD were the most sensitive and specific criteria for surgical follow-up of keratoconus.[23] ISV is an indicator for anterior corneal irregularity and defines the standard deviation of the sagittal radii in the measured eye from the mean curvature. IHD expresses the decentration of height data in the vertical direction. Data on significant improvements in ISV and IHD in the current study showed that PT-ICRS implantation effectively corrected irregularity of the anterior cornea and reduced the eccentricity of the cone. IVA and IHA are similar topometric indices for comparing the upper and lower halves of the cornea. IVA is the mean difference of vertical curvature and IHA is the mean difference of vertical height data, with the horizontal meridian considered as the reflection axis. Our study showed improvements in both IVA and IHA. This finding indicates a remarkable reduction of asymmetry between the upper and lower corneal surfaces [Fig. 3]. The indices of KI and CKI are mainly related to keratoconus severity. KI and CKI values also showed a statistically significant decline. A previous study with data of topometric indices in PT-ICRS implantation reported insignificant CKI change.[17] The study cohort was heterogeneous and consisted of three different keratoconus types: croissant, duck, and snowman phenotypes.[17] Contrarily, our study group consisted of duck-type keratoconus only. The mean CKI in our cohort was 1.07 and higher than in the previous study. In addition, the improvement after PT-ICRS implantation was doubled (0.02 vs. 0.01) and was statistically significant. Barugel *et al*.[15] also studied topometric indices after standard and asymmetric Keraring implantations in duck-type keratoconus, and consistent with our outcomes, they found statistically significant decreases in all topometric indices except IHA. Our study outcomes revealed that PT-ICRS implantation was effective in reducing the severity of keratoconus.

Corneal pachymetry measurements from the thinnest point showed significant thickening after PT-ICRS implantation. The mean increase in thickness was 12 μm. Our finding was in line with a previous study that reported thickening of 12 μm, which the authors hypothesized to be a result of the corneal thickening of tissue organization in the central cornea.[17] We also agree with the hypothesis that the corneal remodeling process may cause corneal thickening after PT-ICRS implantation.

The studies evaluating another asymmetric ICRS model with variable thickness and base width have reported significant improvements in refraction and topography in asymmetric keratoconus types.[24,25] The theoretical finite-element model study done by García de Oteyza *et al*.[26] corroborates our findings of PT-ICRS effectiveness in asymmetric, duck-type keratoconus. The authors found that increasing the ring thickness and base width along the arc of the asymmetric ring segment produced a more pronounced flattening in this part of the ring. They stated that the ring thickness is a more effective parameter than the ring base width in flattening the central and peripheral cornea.

The limitation of the study is the short-term follow-up duration. Another limitation is that it did not include the evaluation of coma and other higher-order aberrations. In addition, the absence of a comparison with a standard ICRS group is a limitation of the study.

Conclusion

In conclusion, PT-ICRS implantation in duck-type keratoconus is an effective and safe treatment. This intervention significantly improves visual acuity, refractive error, and topographic and topometric parameters by reducing both eccentricity and steepness of the cone.

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Conflicts of interest

Efekan Coskunseven is a consultant in Mediphacos Ltd, Minas Gerais, Brazil.

Belma Kayhan declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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