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Intracorneal circular ring implant with femtosecond laser: Pocket versus tunnel

Luis Izquierdo Jr, Ana M Rodríguez, Ramón A Sarquis, Diego Altamirano and Maria A Henriquez

Abstract

Purpose: To evaluate and compare visual and refractive outcomes after implantation of the intracorneal continuous ring 360° arc (ICCR) versus the intracorneal ring segment 340° arc (ICRS) using femtosecond laser for central keratoconus.
Setting: Research Department, Oftalmosalud, Instituto de Ojos, Lima, Peru.
Methods: Randomized study that included 40 eyes of 32 patients diagnosed with central keratoconus between November 2014 and March 2015. Twenty eyes had an implantation of ICCR (MyoRing, Dioptex GmbH, Austria) through an intrastromal pocket and 20 eyes had an implantation of ICRS (Keraring, Mediphacos, Brazil) through an intrastromal tunnel. Both procedures were performed with a femtosecond laser (LDV Z6 model, Ziemer Ophthalmic Systems AG). Visual acuity (VA), refraction, and Scheimpflug imaging analysis were performed pre- and postoperatively at 1 month and 1 year. Comparisons of means were performed using the Student's *t*-test.
Results: At 1 year, uncorrected VA improved 0.77 LogMAR ($p < 0.001$) in the ICCR group and 0.79 LogMAR ($p = 0.01$) in the ICRS group; mean sphere improvement was 5.13 Diopters (D) in the ICCR group and 6.27 D in the ICRS group ($p < 0.001$ both); mean Steeper Keratometry improvement was 4.24 D in the ICCR group and 5.53 D in the ICRS group ($p < 0.001$ both). In the ICCR group, mean decrease in the pachymetry at the thinnest point of the cornea was 32.16 μm ($p = 0.01$), and in the ICRS group, mean increase was 4.2 μm at 1 year ($p = 0.61$).
Conclusion: Intracorneal continuous ring 360° arc (ICCR) and intracorneal ring segment 340° (ICRS) are effective treatments for central keratoconus. No significant differences between rings were found on visual acuity, refraction, and keratometry improvement.

Keywords

Circular intracorneal rings, intrastromal corneal ring, continuous ICR, KeraRing, MyoRing, central keratoconus, femtosecond laser

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Introduction

Keratoconus is an ectatic disorder, where the cornea gradually becomes a conical shape due to a progressive thinning of the corneal stroma, leading to significant visual impairment, irregular astigmatism, and high myopia. It is the second most common cause of corneal transplantation in United States.[1,2]

The intracorneal ring segments (ICR) were approved by the FDA in 1999.[3] It has been postulated that intracorneal rings can cause the anterior surface of cornea to flatten and, therefore, alter the central corneal curvature and corneal steepening in keratoconus patients;[4] Usually one or two ICR are required to correct the conical protrusion of the cornea, however continuous intracorneal rings have been used to treat keratoconus as well,[5–13] specially central or advanced cases of KC, and sometimes they are

Research Department, Oftalmosalud Institute of Eyes, Lima, Peru

Corresponding author:
Maria A Henriquez, Research Department, Instituto de Ojos, Oftalmo Salud, Av. Javier Prado Este 1142, San Isidro, Lima l27, Peru.
Email: mariahenriquez1610@gmail.com

preferred over the conventional segments for this selected cases. Circular rings can be continuous or not, then the intracorneal continuous ring (ICCR) has a 360° arc and the intracorneal ring segment (ICRS) that has a 340° arc; the principal difference between them is that the ICCR needs the creation of a corneal pocket, which disrupts the corneal lamellae in the visual axis, while the ICRS requires the creation of an intrastromal tunnel.[11]

The aim of this study is to compare the visual acuity, refractive changes, and tomographic outcomes in eyes with central keratoconus after ICCR and ICRS implantation.

Methods

This double blind randomized clinical study included patients diagnosed with central keratoconus (keratoconus apex within central 2 mm) at Oftalmosalud Instituto de Ojos, Lima, Peru, between November 2014 and March 2015. The inclusion criteria were a keratoconus diagnosis,[11,12] with stage II, III, and IV keratoconus according to the Amsler-Krumeich classification and to have a central keratoconus pattern which was defined as a keratoconus apex within the central 2 mm and to have topographic pattern according to the classification by Rabinowitz,[13] clear central corneas, uncorrected visual acuity of 0.25 LogMAR or worse, minimum corneal thickness at the thinnest point of 400 μm, and patients had to be 18 years or older. Patients with previous surgeries or any disease other than keratoconus and/or connective tissue or herpetic or patients with stage I keratoconus according to the Amsler-Krumeich classification and a history of recurrent corneal erosions were excluded from the study. The patients were randomly selected for each group. We used a random number generator for the selection of the patients. The ethics committee of the Oftalmosalud approved the study under the principles of the Declaration of Helsinki, and written, informed consent was obtained from all patients.

The ICCR (MyoRing, Dioptex GmbH, Linz, Austria) is a 360° arc continuous full ring implant made of Poly methyl methacrylate (PMMA) which is implanted into a corneal pocket. The diameter of the MyoRing ranges from 5-6 mm and the thickness ranges from 200 to 320 μm in 20 μm intervals. The nomogram for the selection of the Myoring dimension (Table 1) depends only on the value of the central average K-reading according to (SIM K1 + SIMK2)/2. Using the femtosecond laser (Ziemer LDV Z6, Port, Switzerland) a stromal pocket was created with a depth of 300 μm and a diameter of 8.5 mm, with a nasal aperture of 5 mm and the ICCR was inserted using ICCR forceps (Albert Heiss Tuttlingen, Germany) and centered on the corneal reflex coincident with the Pupillary axis.

The ICRS (KeraRing, Mediphacos, Belo Horizonte, Brazil) is a 340° arc continuous ring implant made of PMMA which is implanted into a corneal tunnel. The diameter of the Keraring is 5.5 mm, available in two thicknesses: 200 μm and 300 μm. The nomogram for the selection of the Keraring dimension depends on the subjective refraction and the corneal shape available at http://smmedical.cl/wp-content/uploads/2013/10/Agrupado.pdf. Using the femtosecond laser (Ziemer LDV Z6, Port, Switzerland) the tunnel was created at 80% depth (according to the pachymetry at the thinnest point of the tunnel creation in the cornea, measured with Scheimpflug imaging (Pentacam; Oculus GmbH, Wetzlar, Germany) 5–6 mm area, depending of the nomogram suggestion. The tunnel incision is placed on the steep meridian of the cornea. An inner and external diameter tunnel is created at 0.6 mm and 0.7 mm, respectively with an arc of 359°.

Table 1. Nomogram for ICCR selection.

Mean keratometry (D)	Ring size diameter (mm)	Ring thickness (μm)
<48	6	240
>48–<52	6	280
>52–<55	5	280
>55	5	320

Mean keratometry: (*K*1 + *K*2)/2; D: Diopters; K1: Flat keratometry; K2: Steep keratometry.

Postoperative treatment included topical tobramycin and dexamethasone eye drops every 4 h for 1 week and topical lubricants (sodium hialuronate [Lagricel – Sophia]) every 4 h for 1 month. Pre- and postoperative follow-ups at 1 month and 1 year included uncorrected visual acuity (UCVA), best corrected visual acuity (BCVA), manifest refraction and Scheimpflug imaging analysis (Steeper, flatter, and maximum keratometry (K); posterior elevation with a standard 9 mm best fit sphere (BFS) at the TP (EleBTP); indices of surface variance (ISV); indices of height decentration (IHD); index of vertical asymmetry (IVA); total corneal aberrations (root mean square); asphericity at the front of the cornea; and pachymetry at the apex and the thinnest point (TP) of the cornea were measured and compared.

Statistical analyses were performed with the SPSS (version 12) program. Comparisons of means were performed using the Student's *t*-test. Normality of the data distribution was evaluated using the Kolmogorov–Smirnov test. The chi-square test was used to evaluate proportional differences between follow-up examinations.

Results

Demographics

Forty eyes from 32 patients were included; there were 20 (62.5%) males and 12 (37.5%) females. The mean patients age was 30 years (SD: 6.78 years; range 22–40 years) in the ICCR and 28 years in the ICRS group (SD: 11.65; range 18–48 years). Of the 40 investigated eyes, 20 eyes were treated

Table 2. Preoperative parameters in the Myoring and Kerarings groups.

	Preop Myoring	Preop Keraring	p-Value*
Age	30.15 (7.30)	28.70 (11.22)	0.27
UCVA	1.35 (0.30)	1.31 (0.56)	0.20
BCVA	0.32 (0.14)	0.28 (0.12)	0.82
Sphere	–6.40 (3.38)	–7.60 (4.56)	0.13
Cylinder	–4.54 (1.76)	–4.75 (2.23)	0.48
Flattest K	48.53 (2.77)	48.69 (3.31)	0.54
Steeper K	52.62 (3.14)	54.44 (4.21)	0.19
Kmax	57.45 (3.88)	59.52 (5.13)	0.79
EleBTP	46.54 (17.05)	56.50 (17.34)	0.96
ISV	96.08 (18.41)	92.00 (20.70)	0.56
IHA	21.34 (17.68)	30.09 (16.19)	0.37
IHD	0.08 (0.03)	0.09 (0.05)	0.22
IVA	0.94 (0.34)	0.68 (0.32)	0.49
Total corneal aberrations RMS	10.11 (2.40)	9.68 (4.00)	0.03
Asphericity	–0.88 (0.35)	–1.26 (0.43)	0.90
Spherical Aberration	–0.70 (0.47)	–1.59 (0.57)	0.48
Pachymetry apex	465.85 (38.07)	432.30 (31.45)	0.38
Pachymetry TP	459.85 (38.07)	424.00 (23.24)	0.17

Preoperative visual acuity, refraction and Scheimpflug parameters in the two groups.
UCVA: uncorrected visual acuity; BCVA: best corrected visual acuity; K: keratometry; Kmax: maximum keratometry; EleBTP: elevation back at the thinnest point; ISV: index surface variance; IHA: index of high asymmetry; IHD: indices of height decentration; IVA: index of vertical asymmetry; RMS: root mean square; TP: thinnest point.
p-Value* for comparison between Myoring and Keraring groups.

with femtosecond-assisted MyoRing corneal implantation (Group 1) and 20 eyes with femtosecond assisted Keraring segments (Group 2). Four patients underwent bilateral MyoRing and no patients underwent bilateral with ICRS. Twenty (50%) eyes with stage II, 8 (20%) eyes with stage III and 12 (30%) eyes with stage IV keratoconus according to the Amsler-Krumeich classification.

There was no statistically significant difference between the groups in terms of UCVA, BCVA, Sphere, Cylinder, or Pachymetry at preoperative evaluations ($p \geqslant 0.05$, see Table 2). Table 3 shows pre- and postoperative data at 1 month and 1 year in all parameters studied.

Visual acuity

In the ICCR group, compared with preoperative data, mean UCVA improvement was 0.76 LogMAR ($p < .001$) at 1 month and 0.77 LogMAR ($p < .001$) at 1 year postoperatively. Mean BCVA worsening was 0.03 LogMAR at 1 month ($p = 0.45$), which returned to the baseline at 1 year postoperatively 0.30 LogMAR ($p = 0.81$). In the ICRS group, compared with preoperative data, mean UCVA improvement was 0.83 LogMAR ($p < .001$) at 1 month and 0.79 LogMAR ($p = 0.01$) at 1 year postoperatively. Mean BCVA improvement was 0.01 LogMAR ($p = 0.92$) at 1 month and 0.07 LogMAR ($p = 0.21$) at 1 year postoperatively. None of the eye lost lines of BCVA in either group at 1 year postoperatively.

Spherical component

The mean sphere improvement was 5.13 D in the ICCR group and 6.27 D in the ICRS group at 1 year postoperatively ($p < 0.001$ both). The mean cylinder improvement was 1.69 D in the ICCR group and 2.45 D in the ICRS group at 1 year postoperatively ($p = 0.01$ both). There was no significant difference with respect to the mean change between groups at 1 year ($p = 0.46$).

Keratometry

The mean Steeper Keratometry improvement was 4.24 D in the ICCR group and 5.53 D in the ICRS group at 1 year postoperatively ($p < 0.001$ both). There was no significant difference with respect to the mean change between groups ($p = 0.25$) at 1 year. Figures 1 and 2 show a case with a reduction in the Kmax of 8.8 D and 15 D using the ICCR and the ICRS respectively.

Pachymetry

In the ICCR group, the mean decreases at the thinnest point (TP) of the cornea, at 1 month and 1 year postoperatively, compared with preoperative values was 12.08 µm and 32.16 µm respectively ($p = 0.01$ both). In the ICRS group, mean increase was 12 µm at 1 month ($p = 0.09$) and 4.2 µm at 1 year ($p = 0.61$), respectively.

Table 3. Pre and posterative visual acuity, refraction and Scheimpflug parameters in the two groups.

	Preop	Post 1 m	Post 1 y	*p*-Value*	*p*-Value**	*p*-Value***
Myoring						
UCVA	1.35 (0.30)	0.59 (0.25)	0.58 (0.34)	<0.001	<0.001	0.989
BCVA	0.32 (0.14)	0.35 (0.13)	0.30 (0.19)	0.45	0.81	0.515
Sphere	–6.40 (3.38)	–0.71 (2.72)	–1.27 (1.75)	<0.001	<0.001	0.737
Cylinder	–4.54 (1.76)	–2.98 (0.93)	–2.85 (1.03)	0.02	0.01	0.460
Flattest K	48.53 (2.77)	43.82 (1.84)	44.20 (1.50)	<0.001	<0.001	0.723
Steeper K	52.62 (3.14)	48.00 (3.48)	48.38 (2.54)	<0.001	<0.001	0.248
Kmax	57.45 (3.88)	56.22 (5.42)	56.13 (4.75)	0.37	0.33	0.781
EleBTP	46.54 (17.05)	46.54 (20.69)	50.85 (19.03)	1.00	0.20	0.103
ISV	96.08 (18.41)	101.91 (30.96)	93.54 (25.18)	0.43	0.69	0.265
IHA	21.34 (17.68)	30.21 (16.07)	28.92 (16.61)	0.09	0.23	0.06
IHD	0.08 (0.03)	0.11 (0.06)	0.18 (0.27)	0.05	0.20	0.05
IVA	0.94 (0.34)	1.12 (0.37)	0.95 (0.41)	0.04	0.94	0.10
Total corneal aberration RMS	10.11 (2.40)	12.71 (6.05)	12.03 (4.00)	0.14	0.12	0.15
Asphericity	–0.88 (0.35)	0.10 (0.28)	–0.05 (0.46)	<0.001	<0.001	0.02
Aberration spherical	–0.70 (0.47)	–1.24 (1.03)	–1.08 (0.46)	0.09	0.16	0.04
Pachymetry apex	465.85 (38.07)	447.77 (52.65)	441.92 (53.93)	0.01	0.02	0.02
Pachymetry TP	459.85 (38.07)	447.77 (52.65)	427.69 (59.23)	0.01	0.01	0.01
Keraring						
UCVA	1.28 (0.56)	0.45 (0.25)	0.49 (0.23)	<0.001	0.01	
BCVA	0.28 (0.12)	0.27 (0.17)	0.21 (0.13)	0.92	0.21	
Sphere	–7.60 (4.56)	–1.83 (1.94)	–1.33 (1.28)	<0.001	<0.001	
Cylinder	–4.75 (2.23)	–2.30 (0.82)	–2.30 (1.06)	0.01	0.01	
Flattest K	48.69 (3.31)	44.59 (4.06)	44.81 (4.54)	<0.001	<0.001	
Steeper K	54.44 (4.21)	47.80 (3.19)	48.91 (4.44)	<0.001	<0.001	
Kmax	59.52 (5.13)	59.60 (4.34)	59.64 (5.26)	0.94	0.94	
EleBTP	56.50 (17.34)	64.90 (13.51)	59.80 (14.54)	0.09	0.40	
ISV	92.00 (20.70)	106.90 (25.17)	101.70 (30.73)	<0.001	0.25	
IHA	30.09 (16.19)	20.48 (13.79)	22.11 (14.20)	0.17	0.19	
IHD	0.09 (0.05)	0.17 (0.23)	0.09 (0.04)	0.35	0.87	
IVA	0.68 (0.32)	0.98 (0.48)	0.96 (0.48)	0.01	0.02	
Total corneal aberration RMS	9.68 (4.00)	18.13 (4.98)	17.01 (4.94)	<0.001	<0.001	
Asphericity	–1.26 (0.43)	0.11 (0.59)	–0.10 (0.62)	<0.001	<0.001	
Spherical aberration	–1.59 (0.57)	–0.81 (1.42)	–0.13 (–1.17)	0.04	0.03	
Pachymetry apex	432.30 (31.45)	442.30 (35.00)	435.90 (40.84)	0.01	0.54	
Pachymetry TP	424.00 (23.24)	436.00 (34.12)	428.20 (38.79)	0.09	0.61	

UCVA: uncorrected visual acuity; BCVA: best corrected visual acuity; K: keratometry; Kmax: maximum keratometry; EleBTP: elevation back at the thinnest point; ISV: index surface variance; IHA: index of high asymmetry; IHD: indices of height decentration; IVA: index of vertical asymmetry; RMS: root mean square; TP: thinnest point.
*p-Value between pre and postoperative at 1 month.
**p-Value between pre and postoperative at 1 year.
***p-Value between the two groups, about the change at 1 year.

Adverse effects and postoperative complications

No intraoperative complications occurred in this series of patients. In the ICCR group, there was one patient with cornea edema at 1 week postoperatively with worsening in the visual acuity; this resolved after 3 weeks of treatment with fluorometholone eye drops treatment every 4 h, and the BCVA returned to baseline at 2 months postoperatively.

Discussion

Circular complete intrastromal corneal rings have been proposed first in 2008,[7] different studies have shown efficacy and safety of these rings with no loss of BCVA related with the creation of the central pocket,[5–7] also, their implantations have been associated with higher flattening of the cornea, commonly used in advanced cases of keratoconus, however it remains unclear if a complete 360° (ICCR) or incomplete 340° (ICRS) is the best option

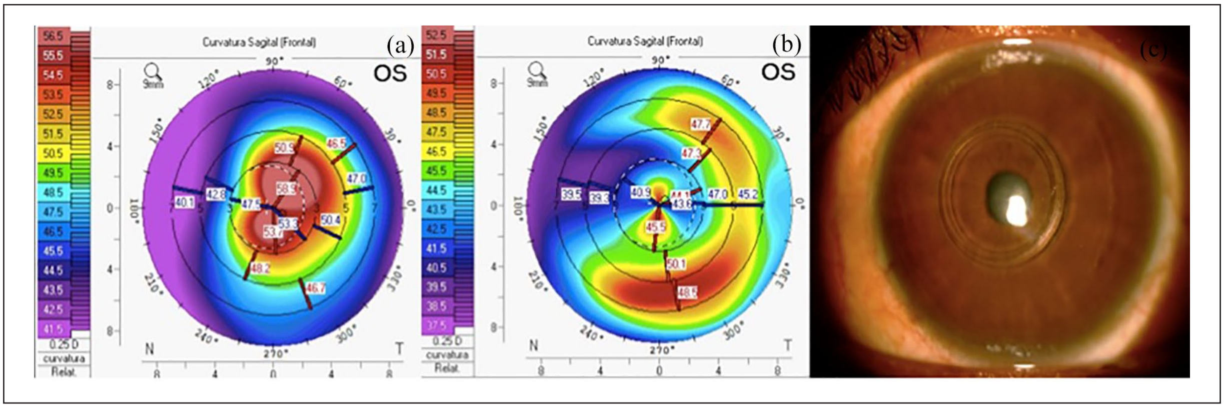

Figure 1. (a) Preoperative curvature map, (b) postoperative curvature map, and (c) Myoring in patient's eye.

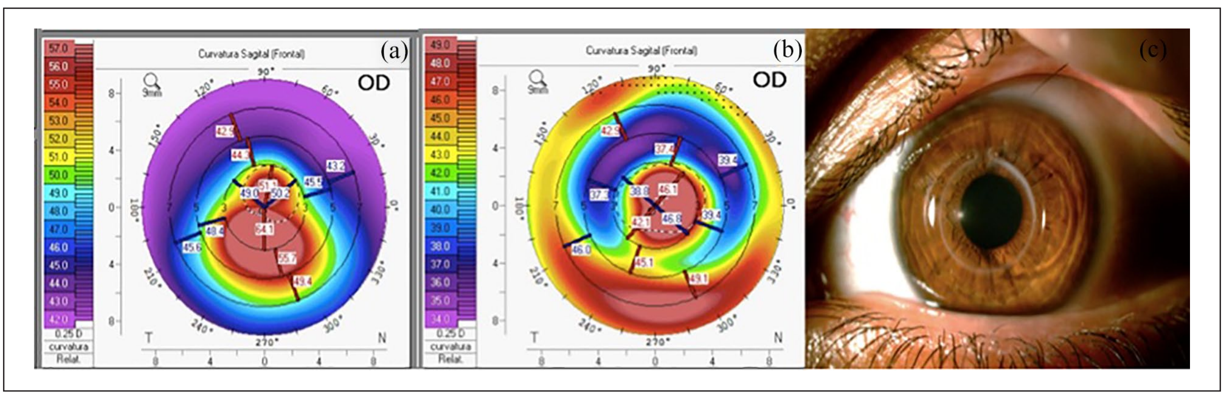

Figure 2. (a) Preoperative curvature map, (b) postoperative curvature map, and (c) Keraring 340° in patient's eye.

for these cases. The aim of this study was to evaluate the refractive results in central keratoconus using two different approaches (pocket versus tunnel) with two different circular corneal rings. Our study found that there were not significant differences in terms of visual acuity, refractive error, and keratometry improvement between the rings suggesting that both ICR are effective to treat selected cases of central keratoconus.

In the group of ICCR we found a significant improvement in UCVA of 0.77 LogMAR, similar to other authors whom found significant improvement between 0.75 to 0.97 LogMAR with follow-up between 6 months to 3 years (Jabbarvand et al.,[6] Daxer et al.,[7] Alio et al.,[8] Mojaled Nobari et al.,[9] Jadidi et al.[14]). On the other hand, in the ICRS group, a significant improvement was found in UCVA of 0.79 LogMAR, similar to Sadoughi et al.[15] whom reported a significant improvement of 0.53 LogMAR.

Similar results have been reported using ICRS, Jadidi et al.[10] found a significant improvement of 0.28 LogMAR using the Keraring of 355°. Recently, Yousif and Said[16] compared visual acuity, refraction and topography of three different intracorneal rings, Keratacs 160-degree two symmetrical ring segment, the Keratacx 320-degree near-total ring, and the Myoring continuous intracorneal ring (ICR) in central keratoconus; The authors of this study also concluded that all three devices were effective to treat central keratoconus treatment, they found a significant improvement with the Myoring group of 0.1 LogMAR.

We did not find significant changes in the BCVA in neither groups, as was the case in the Alio et al.[8] study using the ICCR (Myoring); however, some authors[6,7,10] have reported a significant improvement of BCVA using the ICCR or the ICRS Keraring 355°; The Authors of this study suggest that this improvement could be due because the center of the cornea is fairly regular after surgery;[7] In fact, we did not find any improvement in neither group in the cornea irregularity indexes (ISV, IHD, or IVA). We were expecting to find a difference between groups in terms of these indexes, considering that ICCR insertion compromises the corneal center and the visual axis. But opposite to our hypothesis, IVA worsened in both groups, and it was significant in the ICRS group at 1 year; the IVA is a measure of the mean difference between the superior and inferior corneal curvature, it is the value of curvature symmetry with respect to the horizontal meridian as the axis of reflection, we think that although both rings are centered, the tensile forces of a 360-degree ring must be equal in all directions, while an incomplete one such as 340° tensile forces should not be equal across all diameters resulting in an increase in the IVA. Related to the IHD index, despite Myoring group experienced an increase in postoperative period there was not significant differences for IHD in neither groups.

There was a significant flattening in the steeper keratometry of 4.24 D in the ICCR and 5.53 D in the ICRS group at 1 year postoperatively; Similar flattening has been reported when using the same ICCR, with a range between 4 D and 8.03 D,[6–9] and when using the same ICRS 340°, there was a flattening of 4.8 D.[10] The reported range of flattening using ICRS (1 or 2 segments) was between 2 D and 6 D.[17,18] Complete continuous rings (Myoring) have been associated with higher flattening of the cornea because the circular shape of the ring leads to a more powerful arc-shortening effect as Jabbarvand et al.[6] reported in their study as well. Our results show that incomplete continuous rings 340° arch (Keraring) proved to be just as effective flattening the cornea as the ICCR 360.[6,8] Flattening as high as 10.9 D was observed in the ICCS group and 10.5 D in the ICRS group. Alio et al.[8] suggest that the main reason for great improvement after Myoring ICR implantation is the use of thicker implants with smaller diameters, as well as the selection of higher grades of keratoconus that are more likely to experience a higher flattening effect. In our study, we took into account these variables: the ICCR has a 5 mm diameter and the ICRS has a 5.5 mm diameter, and the means of preoperative steeper keratometry were 52.62 D and 54.44 D, respectively.

The mean significant decrease in the sphere and cylinder at 1 year postoperatively, was 5.13 D and 1.69 D in the ICCR group and 6.27 D and 2.45 D in the ICRS group; our findings are consistent with previous results using the ICCR with a mean decrease in the sphere range from 3.19 D to 5.39 D[6–9] and using the ICRS 340° was 2.13 D.[10] The refractive correction achieved in both groups is larger than the mean correction observed after ICRS inferior to 210°.[19,20] Also, in agreement with a recently review published by our group about effectiveness of different intrastromal corneal rings,[21] were the most robust sphere component improvement was using the MyoRing with a mean reduction of 6.26 D.[21]

Differences in outcomes between the two groups were found in the pachymetry, the ICRS group showed a slight increase in pachymetry, however, a separate statistical analysis not taking into account the patient with edema reveal, whereas the Myoring group showed a significant decrease. Some authors have reported a significant increase in the central corneal thickness after the Myoring implantation[6,8] due to structural changes in the cornea. A review done by Jabbarvand et al.[22] showed that the changes in pachymetry are highly variable between studies after the intracorneal rings. In our study both groups experienced structural changes in the cornea due to the procedure itself, but with some differences, the Myoring is a complete 360° ICR that needs the creation of a corneal pocket, disrupting the corneal lamellae in the visual axis, while the Keraring is a 340° ring that requires the creation of an intrastromal tunnel; we could hypothesize that the differences in pachymetry are due to an artifact or to some lamellae compaction that occurs in the postoperative period of the Myoring group that these parameters sometimes the pentacam could misinterpret. Similar to the Myoring procedure, in which the central cornea is altered, is the small aperture cornea inlay and the corneal collagen crosslinking. The small aperture cornea inlay as not been associated with thinning of the cornea,[23] while corneal collagen crosslinking has been associated with postoperative thinning when it is measured using optical pachymetry and it is attributed to an artifact after treatment suspected to be a consequence of the tissue refractive index change in the area of the demarcation line or the postoperative corneal haze.[24,25]

In addition to visual and refractive outcomes, changes in the total corneal aberrations were also evaluated in this study, the overall amount total corneal aberrations RMS did not change significantly with the ICCR implantation but increased significantly in the ICRS group; Unlike Piñero et al.,[13] who showed not changes in total corneal aberrations RMS at 6 months after ICRS. Jabbarvand et al.[22] found that higher order aberrations and coma-like aberrations decreased significantly, but spherical aberrations increased after Myoring implantation, comparing these results with our study we found that the spherical aberration in the ICCR group had a significant increase. We believe that these changes could be expected because of the flattening effect of the central cornea and the change in the shape of the cornea from prolate to oblate comparing the ICCR and the ICRS groups. However, there were not significant differences between groups on the change in spherical aberration. Furthermore, an increase in corneal asphericity, was induced in both groups, and could be explained because the circular shape and small size of corneal rings used in this study.

In relation to the complications, no intraoperative or post-operative complications occurred in this series of patients. Compared with others authors, Vega-Estrada et al.[26] had five of the 30 cases needed to be explanted because of severe focal corneal melting. The author used a new asymmetric 353-degree arc length ICRS, named the Visumring which can be customized. Some differences between the ICRS arc could be related to these complications, the long arc length of ICRS used in their study could makes the ends fall beneath the corneal incision whereas the tip of the implant of the ICRS Keraring 340° is located away from the corneal incision. Some limitation of our study is the small sample size and that we did not evaluate halos or glare objectively.

In conclusion, this study shows that the Intracorneal continuous ring 360° arc and the intracorneal ring segment 340° arc used in central keratoconus improves both UDVA and CDVA significantly. It is a safe and minimally invasive procedure that provides favorable clinical outcomes. It also reduces significantly the spherical power of the cornea and keratometry with no significant differences between rings on visual acuity, refraction and keratometry improvement. Additionally, However, further randomized, multi-centric prospective studies are needed to confirm the stability of these findings.

Authors' note

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ORCID iDs

Luis Izquierdo Jr https://orcid.org/0000-0002-9405-4581
Maria A Henriquez https://orcid.org/0000-0001-9392-5536

References

1. Rabinowitz YS. Keratoconus. *Surv Ophthalmol* 1998; 42: 297–319.
2. Eye Bank Association of America. Eye banking satistical report. Washington, DC: Eye Bank Association of America, 2014.
3. Asbell PA and Uçakhan ÖÖ, Long-term follow-up of Intacs from a single center. *J Cataract Refract Surg* 2001; 27: 1456–1468.
4. Candelaria A and Campos M. Intrastromal corneal ring segments. In: Krachmer JH, Mannis MJ and Holland EJ (eds) *Cornea*. 3rd ed. St. Louis: Mosby; 2011, p.1893.
5. Mahmood H, Venkateswaran RS and Daxer A. Implantation of complete corneal ring in an intrastromal pocket for keratoconus. *J Refract Surg* 2011; 27: 63–68.
6. Jabbarvand M, Salamatrad A, Hashemian H, et al. Continuous intracorneal ring implantation for keratoconus using a femtosecond laser. *J Cataract Refract Surg* 2013; 39: 1081–1087.
7. Daxer A, Mahmoud H and Venkateswaran RS. Intracorneal continuous ring implantation for keratoconus: one-year follow-up. *J Cataract Refract Surg* 2010; 36: 1296–1302.
8. Alio JL, Pinero DP and Daxer A. Clinical outcomes after complete ring implantation in corneal ectasia using the femtosecond technology; a pilot study. *Ophthalmology* 2011; 118: 1282–1290.
9. Nobari S, Villena C and Jadidi K. Full ring intracorneal implantation in corneas with pellucid marginal degeneration. *Iran Red Crescent Med J* 2015; 26: 17.
10. Jadidi K, Mosavi SA, Nejat F, et al. Intrastromal corneal ring segment implantation (keraring 355°) in patients with central keratoconus: 6-month follow-up. *J Ophthalmol* 2015; 2015: 916385.
11. Hosny M, El-Mayah E, Sidky MK, et al. Femtosecond laser-assisted implantation of complete versus incomplete rings for keratoconus treatment. *Clin Ophthalmol* 2015; 9: 121–127.
12. Haddad W, Fadlallah A, Dirani A, et al. Comparison of 2 types of intrastromal corneal ring segments for keratoconus. *J Cataract Refract Surg* 2012; 38: 1214–1221.
13. Piñero DP, Alio JL, El Kady B, et al. Refractive and aberrometric outcomes of intracorneal ring segments for keratoconus: mechanical versus femtosecond-assisted procedures. *Ophthalmology* 2009; 116: 1675–1687.
14. Janani L, Jadidi K, Mosavi SA, et al. MyoRing implantation in keratoconic patients: 3 years follow-up data. *J Ophthalmic Vis Res* 2016; 11: 26–31.
15. Sadoughi MM, Einollahi B, Veisi AR, et al. Femtosecond laser implantation of a 340-degree intrastromal corneal ring segment in keratoconus: short-term outcomes. *J Cataract Refract Surg* 2017; 43(10): 1251–1256.
16. Yousif MO and Said AMA. Comparative study of 3 intracorneal implant types to manage central keratoconus. *J Cataract Refract Surg* 2018; 44(3): 295–305.
17. Vega-Estrada A and Alio JL. The use of intracorneal ring segments in keratoconus. *Eye Vis (Lond)* 2016; 3(1): 1–7.
18. Ziaei M, Barsam A, Shamie N, et al. Reshaping procedures for the surgical management of corneal ectasia. *J Cataract Refract Surg* 2015; 41: 842–872.
19. El-Raggal TM and Fattah AA. Sequential Intacts and Verisyse phakic intraocular lens for refractive improvement in keratoconic eyes. *J Cataract Refract Surg* 2007; 33: 966–970.
20. Coskunseven E, Onder M, Kymionis GD, et al. Combined intacts and posterior chamber toric implantable collamer lens implantation for keratoconic patients with extreme myopia. *Am J Ophthalmol* 2007; 144: 387–389.
21. Izquierdo L, Mannis MJ, Smith JA, et al. Effectiveness of intrastromal corneal ring implantation in the treatment of adult patients with keratoconus: a systematic review. *J Refract Surg* 1995; 35(3): 191–200.
22. Jabbarvand M, SalamatRad A, Hashemian H, et al. Continuous corneal intrastromal ring implantation for treatment of keratoconus in an Iranian population. *Am J Ophthalmol* 2013; 155: 837–842.
23. Seyeddain O, Bachernegg A, Riha W, et al. Femtosecond laser–assisted small-aperture corneal inlay implantation for corneal compensation of presbyopia: two-year follow-up. *J Cataract Refract Surg* 2013; 39: 234–241.
24. Caporossi A, Mazzotta C, Baiocchi S, et al. Long-term results of riboflavin ultraviolet A corneal collagen cross-linking for keratoconus in Italy: the Siena eye cross study. *Am J Ophthalmol* 2010; 149: 585–593.
25. Raiskup-Wolf F, Hoyer A, Spoerl E, et al. Collagen crosslinking with riboflavin and ultraviolet-A light in keratoconus: long-term results. *J Cataract Refract Surg* 2008; 34: 796–801.
26. Vega-Estrada A, Chorro E, Sewelam A, et al. Clinical outcomes of a new asymmetric intracorneal ring segment for the treatment of keratoconus. *Cornea* 2019; 38(10): 1228–1232.