Ferrara intracorneal ring segments for keratoconus

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Purpose: To assess the outcome of Ferrara intracorneal ring segments for keratoconus.

Setting: Private practice and university hospital, Porto Alegre, Brazil.

Methods: In this retrospective noncomparative interventional case series, 51 keratoconus eyes of 47 patients that had Ferrara intracorneal ring segment implantation were reviewed. Uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), central corneal curvature, corneal astigmatism, surface regularity index, surface asymmetry index, and complications were analyzed.

Results: At a mean follow-up of 13.0 months ± 8.7 (SD), the BSCVA improved in 86.4% of eyes, was unchanged in 1.9%, and worsened in 11.7%. The UCVA improved in 86.4% of eyes, was unchanged in 7.8%, and worsened in 5.8%. The mean spherical equivalent (SE) was reduced from −6.08 ± 5.01 diopters (D) to −4.55 ± 5.71 D and the mean refractive astigmatism, from −3.82 ± 2.13 D to −2.16 ± 2.07 D. The mean central corneal curvature was reduced from 48.76 ± 3.97 D to 43.17 ± 4.79 D. Eyes with central keratoconus had statistically significantly better results than eyes with inferior keratoconus in topographic astigmatism, SE, and refraction cylinder. Penetrating keratoplasty was avoided in 38 eyes (74.5%) during the follow-up. Intracorneal ring segment decentration occurred in 2 eyes (3.9%), segment extrusion in 10 eyes (19.6%), bacterial keratitis in 1 eye (1.9%) with segment extrusion, and a disciform keratitis in 1 eye (1.9%).

Conclusion: Implantation of Ferrara intracorneal ring segments in patients with keratoconus was a safe and reversible procedure that led to stable results and avoided or delayed PKP in many cases.

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Keratoconus is a leading causes of corneal blindness and a common indication for penetrating keratoplasty (PKP).[1] One of the most effective methods of visual rehabilitation in keratoconus patients is rigid contact lenses, but a high percentage of these patients are contact-lens intolerant. Various surgical procedures have been suggested as alternatives to PKP for keratoconus, including apex cauterization, epikeratophakia, sectorial keratotomy, photorefractive keratectomy (PRK), laser in situ keratomileusis (LASIK), and lamellar keratoplasty, but they have had disappointing results.[2]

In the mid-1950s, Barraquer[3] suggested using intrastromal implants in the corneal midperiphery to correct myopia and astigmatism. Poly(methyl methacrylate) (PMMA) biocompatibility, a low rejection rate of PMMA implants, and reasonable predictability of the implants were stressed in many studies.[4–7] Intracorneal ring segments (ICRS) for the correction of low myopia (up to −3.00 diopters [D]) were recently approved by the U.S. Food and Drug Administration (FDA).[8–12] Implantation of Intacs (Additional Technology) has been shown to be a safe and reversible procedure.[13] Furthermore, ICRS tend to preserve corneal asphericity, which contributes to better visual acuity and contrast sensitivity.[14,15]

In 1986, Ferrara started implanting modified PMMA rings in rabbit corneas and in 1994, developed a better technique of corneal stromal tunnel construc-

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tion for implanting the rings.[16] In 1996, he replaced the single ring with 2 segments with 160-degrees of arc, improving results for high myopia, and also began to implant the segments in corneas with keratoconus and after PKP.[16]

Recently, others have suggested the use of Intacs ring segments in keratoconus with safe and good results,[17] avoiding or delaying PKP in many patients.[18] In this report, we describe our results with Ferrara ICRS (FICRS) in eyes with keratoconus.

Patients and Methods

Surgery was performed in 51 eyes of 47 patients with keratoconus. All patients were contact-lens intolerant and were waiting for PKP to restore visual acuity. Keratoconus was stage II or III by Amsler classification,[19] and there was no central corneal opacity. Only patients with a minimum follow-up of 3 months were included.

All patients had a complete eye examination including corneal topography (Tomey TMS-2) and central and peripheral corneal pachymetry (Omega, Storz) 5.0 mm from the central cornea in all 4 quadrants.

Ring segments were made of acrylic Perspex CQ (Mediphacos) with an inner radius of curvature of 2.5 mm, thickness from 150 to 350 μm, and arc length between 120 degrees and 160 degrees. The ring segments have a prism format; the flat posterior surface is implanted facing the corneal endothelium. Optical correction is achieved with central corneal flattening, which is directly proportional to the ring thickness.[14] Ring segment thickness and arc lengths were selected according to a previously described Ferrara nomogram.[16] The nomogram suggests changing the ring thickness depending on the keratoconus intensity; ie, 200 μm segment for stage I keratoconus, 250 μm segment for stage II, 300 μm segment for stage III, and 350 μm segment for stage IV.

Surgical Technique

Preoperative topical medication included tobramycin 0.3% and ketorolac drops every 30 minutes starting 2 hours before surgery. All surgery was performed by the same surgeon (S.K.) using the same technique, topical anesthesia (proximetacaine 0.5%), and an operating microscope (Topcon OMS-610).

The central corneal reflex was marked while the patient looked at the center of the coaxial microscope bulb filament. Optical zones of 3.0 mm, 5.0 mm, and 7.0 mm were marked with an appropriate marker tinted with methylene blue.

Two 1.0 mm radial corneal incisions, 180 degrees from each other, were made at the steep corneal meridian (based on preoperative corneal topography) between optical zones of 5.0 mm and 6.0 mm using a double-sided, guided radial keratotomy (RK) diamond knife (DGH-KOI Inc.) set at a depth of 70% (14 eyes) or 80% (37 eyes) of the local corneal pachymetry. This was done to create a stromal tunnel at approximately 50% of corneal thickness. The 2 radial incisions were made in the steep corneal meridian so the ring segments would be implanted in the flat corneal meridian to achieve corneal flattening at the opposite steep meridian.

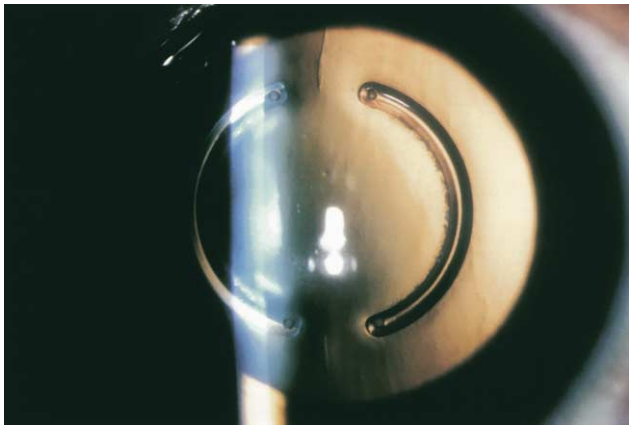

Figure 1. (Kwitko) Ring segments implanted inside the stromal tunnel.

Two concentric stromal corneal tunnels with an internal radius of curvature of 2.5 mm and an extension of 170 degrees were constructed with a Ferrara double-curved spatula (Ferrara Ophthalmics); the ring segments were implanted in the tunnels (Figure 1). If the opening of 1 tunnel was located in the inferior corneal quadrant, it was closed with a single 10-0 nylon radial suture, which was removed on day 30.

Ketorolac drops were used every 15 minutes for 3 hours after surgery, and a combination of 0.1% dexamethasone and 0.3% tobramycin drops was used every 4 hours for 7 days, as well as methylcellulose 0.5% every 6 hours for 30 days.

Postoperative Evaluation

Snellen uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), central corneal curvature, corneal astigmatism, surface regularity index (SRI), and surface asymmetry index (SAI), all measured by corneal topography, were evaluated every 30 days during the first 6 months and then every 6 months. Complications such as ring decentration, extrusion, and/or infection were also evaluated.

Statistical Analysis

Results were analyzed with Statview for Windows software (5.0.1 version, SAS Institute Inc.). The paired *t* test was used in all results except preoperative central versus inferior keratoconus, which was analyzed with the unpaired *t* test.

Results

Fifty-one eyes of 47 keratoconus patients had FICRS implantation. Computerized corneal topography disclosed inferior keratoconus in 27 eyes and central keratoconus in 24 eyes. Forty-three eyes received 300 μm ring segments; 5 eyes, 250 μm segments; and 3 eyes, 350 μm segments. The mean follow-up was 13.0 months ± 7.7 (SD) (range 3 to 39 months).

Preoperative and postoperative data are shown in Tables 1 and 2, respectively. The UCVA improved in 44 eyes (86.4%), did not change in 3 eyes (7.8%), and worsened in 3 eyes (5.8%). The BSCVA improved in 44 eyes (86.4%), did not change in 1 eye (1.9%), and worsened in 6 eyes (11.7%).

Preoperative refraction could be performed in 31 eyes. Postoperative refraction could be performed in all 51 eyes; the mean spherical equivalent (SE) was −4.55 ± 5.71 D and the mean refractive astigmatism, −2.16 ± 2.07 D. In these patients, the mean SE decreased from −6.08 ± 5.01 D preoperatively to −3.81 ± 3.99 D at the last examination ($P<.01$). The mean refractive astigmatism decreased from 3.69 ± 2.20 D preoperatively to 2.12 ± 1.96 D postoperatively ($P<.01$).

The mean central corneal curvature decreased from 48.76 ± 3.97 D preoperatively to 43.17 ± 4.79 D at the last examination (Figures 2 and 3) ($P<.001$). The mean topographic corneal astigmatism decreased from 6.44 ± 2.97 D preoperatively to 4.81 ± 2.93 D postoperatively ($P<.01$). The SRI decreased from 1.99 ± 0.68 to 1.83 ± 0.56, which was not significant ($P = .3373$), and the SAI increased from 3.25 ± 1.81 to 3.36 ± 2.18, also not significant ($P = .9440$).

Based on the preoperative corneal topography, the SRI index varied between central and inferior keratoconus. The central keratoconus group had a statistically significantly higher preoperative SRI (2.25 ± 0.68 D) than the inferior keratoconus group (1.73 ± 0.57 D) ($P<.05$).

Postoperatively, the central keratoconus group had statistically significantly better results than the inferior keratoconus group in topographic astigmatism (central, 7.27 ± 2.92 D to 5.71 ± 2.87 D [$P<.01$]; inferior, 5.71 ± 2.87 D to 4.61 ± 2.95 D [$P>.05$]), SE (central, −6.87 ± 6.03 D to −5.81 ± 6.85 D [$P<.05$]; inferior, −5.34 ± 3.89 D to −3.44 ± 4.29 D [$P>.05$]), and refraction cylinder (central, −4.21 ± 2.31 D to −1.91 ± 1.79 D [$P<.05$]; inferior, −3.47 ± 1.97 D to −2.38 ± 2.29 D [$P>.05$]). Central corneal curvature, SRI, SAI, UCVA, and BSCVA were not statistically significantly different in central and inferior keratoconus eyes.

During the follow-up, 13 eyes (25.5%) of 11 patients required an additional PKP; 3 because of no improvement in BSCVA (cases 2, 21, and 48), 5 because of segment extrusion (cases 4, 15, 22, 23, and 47), 4 because of poor-quality visual acuity (cases 11, 19, 20, and 28), and 1 because of segment decentration (case 30). Penetrating keratoplasty was not necessary for visual rehabilitation in the other 38 eyes (74.5%).

Postoperative complications included the following: (1) ring decentration in 2 eyes (15 and 30) (3.9%) because of blunt trauma at 3 months and 7 months, respectively; (2) ring extrusion in 10 eyes (19.6%), 5 after blunt trauma (eyes 1, 9, 15, 29, and 47) at 2 to 7 months and 5 spontaneously (eyes 4, 22 [twice], 23, and 31) between 4 months and 5 months (Figure 4); in 5 of the 10 eyes, the radial incisions were at 70% of the local corneal pachymetry (35.7% of 14 eyes that received FICRS at this pachymetry versus 13.5% of 37 eyes that received FICRS with the radial incision depth at 80% of the local pachymetry); (3) disciform keratitis adjacent to the segment in 1 eye (4) (1.9%) at 7 months (Figure 5); with treatment of topical prednisolone 1%, the corneal edema resolved, but PKP was necessary after 6 months because visual acuity with the FICRS did not improve; and (4) presumed bacterial keratitis (*Staphylococcus epidermidis*) in 1 eye (15) (1.9%) after ring extrusion (culture was negative, and the diagnosis was based on clinical findings) (Figure 6); the infection cleared after ring removal and 15 days of intense topical treatment with ofloxacin, as well as irrigation of the corneal tunnel with fortified cephalothin, and visual acuity subsequently returned to the preoperative level.

Discussion

Intracorneal implantation of a synthetic material to correct spherical and cylindrical refractive errors is not a new idea. The effect of intracorneal rings or segments in correcting myopia and reducing keratoconus and irregular astigmatism is explained by the Barra-

Table 1. Preoperative data.

Case	SE (D)	BSCVA	UCVA	Central K (mm)	TA
1	−2.00	CF 2 m	CF 50 cm	51.19	7.38
2	3.50	20/100	20/100	40.78	11.72
3	−9.00	20/50	20/200	49.88	9.02
4	Impossible*	20/80	20/80	58.02	1.27
5	−8.50	20/200	CF 2 m	48.28	5.72
6	−1.50	20/80	20/200	50.21	4.49
7	−11.50	20/200	CF 1 m	51.48	5.92
8	−6.00	20/70	20/400	51.79	8.23
9	−20.00	20/400	CF 1 m	45.50	5.9
10	Impossible	20/400	20/400	45.03	8.91
11	Impossible	CF 50 cm	CF 50 cm	40.38	7.96
12	0.00	20/70	20/400	52.93	0.66
13	0.00	20/70	20/400	51.71	2.30
14	Impossible	CF 2 m	CF 2 m	46.71	7.71
15	Impossible	20/400	CF 50 cm	57.02	4.55
16	−9.50	20/50	CF 1 m	47.54	5.5
17	−5.75	20/200	20/400	51.08	2.56
18	−10.50	20/30	CF 1 m	48.88	4.23
19	Impossible	CF 1 m	CF 1 m	50.55	8.2
20	Impossible	CF 50 cm	CF 50 cm	44.42	6.34
21	Impossible	20/200	20/200	45.91	4.73
22	−2.75	20/80	20/200	49.55	12.76
23	Impossible	20/400	20/400	48.07	7.65
24	−14.00	20/60	CF 1 m	45.33	2.74
25	Impossible	CF 2 m	CF 2 m	48.17	8.41
26	−3.25	20/200	CF 2 m	51.70	5.46
27	−2.50	20/70	20/100	54.45	3.52
28	−7.50	CF 3 m	CF 3 m	55.60	9.05
29	−7.50	20/70	20/200	48.93	5.15
30	Impossible	CF 3 m	20/400	53.14	6.96
31	Impossible	20/400	20/400	55.36	2.73
32	−3.75	20/40	20/400	48.85	8.33
33	−3.75	20/200	CF 2 m	44.65	9.28
34	−3.75	20/400	20/400	50.33	9.4
35	−6.00	20/80	20/400	50.08	4.85
36	Impossible	CF 50 cm	CF 50 cm	50.20	6.36
37	−6.25	20/40	CF 2 m	48.22	2.34
38	−3.75	20/60	20/400	46.02	2.80
39	Impossible	20/200	20/200	43.57	8.18
40	Impossible	CF 2 m	CF 2 m	51.37	6.50
41	−2.88	20/50	20/200	49.40	2.17
42	Impossible	CF 3 m	CF 3 m	48.44	6.65
43	Impossible	20/70	20/400	49.38	11.65
44	−7.50	20/40	CF 2 m	43.82	4.41
45	−3.25	20/400	20/200	46.88	9.23
46	−3.50	20/80	20/400	43.62	10.12
47	−7.75	20/200	20/400	50.75	8.11
48	−17.50	20/100	CF 50 cm	52.20	8.55
49	Impossible	20/200	20/200	45.87	3.40
50	Impossible	20/200	20/200	48.73	5.35
51	−8.00	20/200	20/400	41.04	13.10

BSCVA = best spectacle-corrected visual acuity; CF = count fingers; K = keratometry; SE = sperical equivalent; TA = topographic astigmatism; UCVA = uncorrected visual acuity.

*No refraction could be done preoperatively.

Table 2. Postoperative data.

Case	SE (D)	BSCVA	UCVA	Central K (mm)	TA	Note	Follow-up (Mo)
1	−1.50	20/100	20/100	46.06	2.39	Segment extrusion after trauma, explantation	8
2	0.00	20/200	20/200	44.17	15.22	PKP	9
3	−1.50	20/25	20/50	43.88	4.21		35
4	−6.00	20/80	20/200	54.66	7.86	PKP, disciform keratitis with segment extrusion	10
5	−0.50	20/50	20/50	45.32	5.51		15
6	−4.25	20/40	20/50	43.87	3.22		6
7	−5.25	20/100	20/200	47.83	4.85		5
8	−5.50	20/60	20/100	39.19	8.46		6
9	−16.00	20/200	20/80	33.85	1.68	Segment extrusion after trauma, explantation	18
10	1.75	20/50	20/100	48.64	5.22		9
11	−25.75	20/70	20/400	42.21	7.36	PKP	8
12	−1.25	20/30	20/40	45.74	3.10		29
13	−1.25	20/100	20/200	45.31	3.49		17
14	2.75	20/40	20/60	39.49	5.65		23
15	−4.00	20/100	20/400	46.02	4.31	Traumatic decentration and extrusion, keratitis, waiting for PKP	27
16	−4.00	20/40	20/80	44.78	6.49		21
17	−2.00	20/30	20/30	45.15	4.46		7
18	−3.00	20/25	20/50	42.86	3.01		7
19	−7.75	20/80	20/80	39.20	15.48	Waiting for PKP due to poor visual quality	17
20	−13.50	20/60	CF 50 cm	42.86	4.91	Poor visual quality, doesn't want PKP	11
21	3.75	20/400	20/400	39.96	1.80	PKP	23
22	−4.00	20/70	20/20	36.02	3.67	PKP after spontaneous segment extrusion	18
23	−1.50	20/100	20/200	34.52	7.13	Spontaneous segment extrusion, waiting for PKP	11
24	−6.75	20/30	20/60	44.74	1.48		3
25	−20.5	20/60	CF 2 m	49.63	4.33		3
26	−7.50	20/30	20/100	49.79	4.49		25
27	−8.50	20/30	20/70	48.22	2.25		21
28	−6.75	20/60	20/100	38.78	7.16	PKP due to poor visual quality	7
29	−1.25	20/40	20/50	50.93	1.45	Segment extrusion after trauma	9
30	0.00	20/70	20/70	38.27	3.45	PKP after segment decentration following trauma	22
31	−3.25	20/100	20/400	33.79	5.58	Spontaneous segment extrusion	16
32	−4.50	20/50	20/200	45.82	1.07		17
33	−2.50	20/60	20/80	40.94	7.25		3
34	−7.75	20/50	20/100	44.22	1.65		6
35	−2.00	20/40	20/50	49.70	1.10		20
36	−4.00	20/50	20/60	47.14	2.16		22
37	1.75	20/30	20/40	38.36	3.58		8
38	−1.00	20/25	20/80	38.93	5.24		5
39	−2.75	20/40	20/80	42.24	4.70		7
40	−14.87	20/30	20/100	49.77	2.34		4
41	1.25	20/70	20/100	41.34	6.14		5
42	−8.50	20/70	20/400	37.92	8.15	Keratoconus associated with pellucid degeneration	4
43	0.25	20/25	20/80	44.13	5.55		12
44	−4.50	20/30	20/30	37.61	3.38		12
45	−0.75	20/30	20/400	44.70	4.20		6
46	−2.00	20/20	20/100	42.68	3.24		3
47	−11.00	20/70	20/400	48.43	2.23	PKP after segment extrusion following trauma	39
48	−11.25	20/60	20/400	47.52	5.39	PKP	10
49	−1.75	20/30	20/60	38.80	4.85		13
50	−2.25	20/50	20/60	38.80	5.48		12
51	0.00	20/50	20/50	36.70	7.89		13

BSCVA = best spectacle-corrected visual acuity; CF = count fingers; K = keratometry; PKP = penetrating keratoplasty; SE = spherical equivalent; TA = topographic astigmatism; UCVA = uncorrected visual acuity

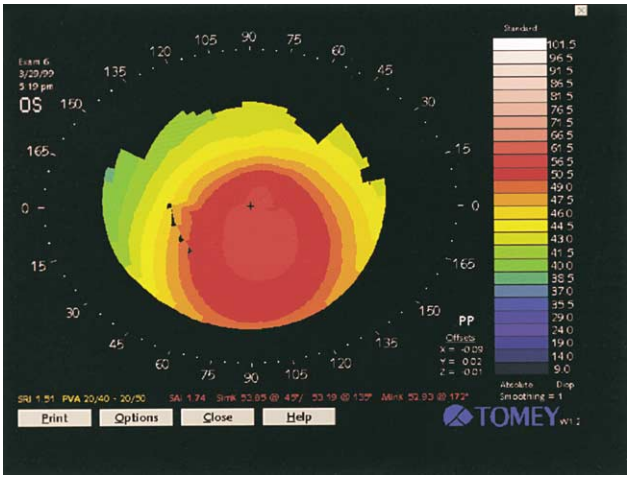

Figure 2. (Kwitko) Example of a preoperative topographic map of an eye with keratoconus (case 10)

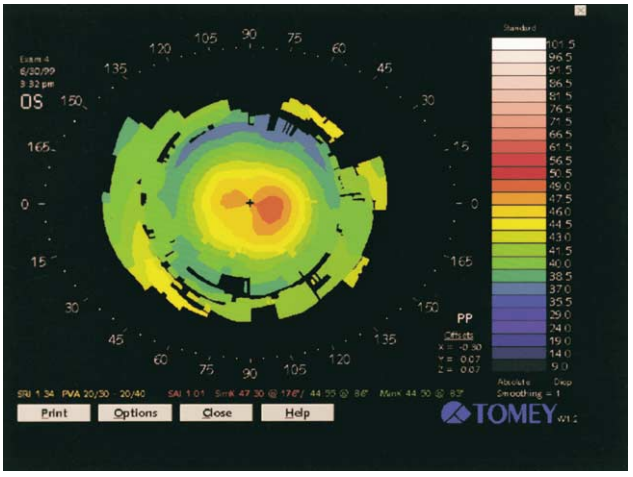

Figure 3. (Kwitko) Eye in Figure 2, 6 months after FICRS implantation.

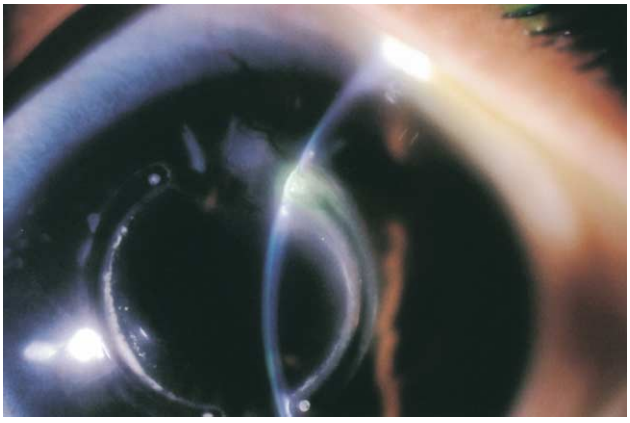

Figure 4. (Kwitko) Ring extrusion 5 months after implantation (case 31).

quer thickness law, which states that central corneal flattening is achieved by adding tissue to the corneal periphery.[3]

Ferrara's ring segments differ from Intacs in 2 aspects: They have a 1.5 mm radius of curvature instead of the 3.5 mm radius of Intacs, and they have a triangular anterior shape instead of the flat anterior surface of Intacs.[20] We think the triangular anterior shape and flat posterior shape of Ferrara ring segments might have a stronger effect on central corneal flattening in keratoconus patients. Besides adding tissue to the corneal midperiphery, the tips of FICRS lift anteriorly after implantation, adding an extra flattening effect in the meridian opposite implantation.

Several studies show that intracorneal PMMA ring implantation is a safe and predictable procedure, with

Figure 5. (Kwitko) Disciform keratitis adjacent to the implanted ring segment (case 4) 7 months after surgery.

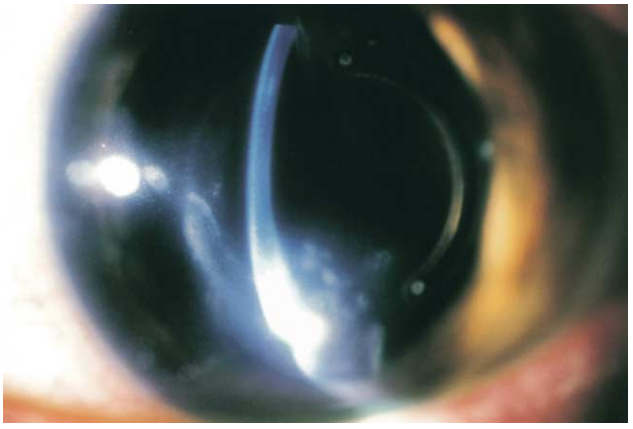

Figure 6. (Kwitko) Pesumed bacterial keratitis after ring extrusion (case 15).

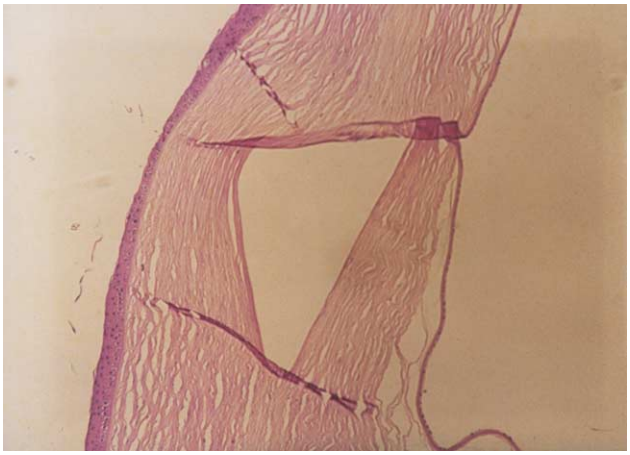

Figure 7. (Kwitko) Histology of case 2 showing the correct position of the FICRS with the flat surface facing down. Note thinning of the epithelial layer above the segment and no inflammatory reaction around it.

preservation of BSCVA in most cases and stable results over time.[10,12] This surgery has the advantages of preserving the central cornea and of being a reversible procedure with a return to preoperative corneal and refractive parameters after ring removal in most cases.[8,9,11,17]

There is also some evidence of less disturbance of the blood–aqueous barrier with this surgery than with PRK or LASIK, as well as preservation of endothelial cell integrity.[21] In addition, there is excellent corneal tolerance to PMMA rings with only short-term, low-grade inflammatory stromal reaction consisting of a discrete concentration of inflammatory cells adjacent to the rings.[22] Figure 7 shows the histology in case 2 in our series; there are no inflammatory cells around the segment.

Improvement in implantation techniques and ring manufacture and methods that provide precise corneal surface evaluation led to FDA approval of PMMA segments (Intacs) for the correction of low myopia.[8–12]

Ferrara was 1 of the first authors to suggest implantation of PMMA ring segments to correct keratoconus and irregular astigmatism.[16] In the initial study, he reported using FICRS to correct high myopia (up to −20.00 D), myopic and compound regular astigmatism, and irregular astigmatism due to keratoconus and PKP. He reported a significant reduction in SE (from −10.20 ± 5.98 D to −2.02 ± 2.02 D) and cylinder (from −4.09 ± 2.42 D to −1.89 ± 1.31 D) after surgery with preservation of corneal asphericity and improvement in contrast sensitivity, BSCVA, and the topography pattern.[16]

We also obtained a significant reduction in SE and cylinder in all eyes. However, topographic corneal regularity and symmetry measured by topography surface indexes did not change significantly. Holmes-Higgin et al.[23] also found no correlation between preoperative and postoperative BSCVA and predicted corneal visual acuity, a topographically derived index, in nonkeratoconus patients who had had intrastromal corneal ring implantation.

In our series of keratoconus patients, 44 eyes (86.3%) had improvement in UCVA and BSCVA. In the follow-up, 39 eyes (76.5%) did not require PKP. Colin et al.[17] also found improvement in mean UCVA and BSCVA in 10 keratoconus patients with Intacs with a follow-up of 12 months.

In our series, postoperative topographic astigmatism, SE, and refractive cylinder were better in eyes with central keratoconus than in eyes with inferior keratoconus. A thinner central cornea (far from the peripheral ring implantation site) and more normal peripheral corneal thickness in eyes with central keratoconus may explain the better results in these eyes; the thin central cornea might be more able to flatten than a thick cornea (when the keratoconus apex is located inferiorly). Another factor that might contribute to this finding is that a less resistant, thin inferior cornea in inferior keratoconus may not support the implanted ring in that area as well. A keratoconus apex located in the center of the implanted rings may also contribute to more postoperative central corneal flattening.

We cannot be certain of the depth of the tunnels used, and different depths of segment implantation may contribute to a better or worse response to this procedure. Furthermore, if the 2 ring segments are implanted at different depths or if a segment is not exactly parallel to the anterior surface of the cornea, induction of astigmatism and lack of keratoconus correction may occur.

A possible intraoperative complication of intracorneal ring implantation is perforation during tunnel construction, as reported by Schanzlin et al. with Intacs.[20] With the Ferrara technique of tunnel construction,[16] we did not have this complication, although we operated on nongrafted corneas only.

Postoperative complications were mainly due to blunt trauma and to a shallow tunnel depth, with spontaneous ring extrusion in 5 eyes. In 5 of the 10 cases (19.6%) of ring extrusion, the radial incision was 70% of the corneal thickness instead of 80%, which may account for shallow tunnel construction. The Intacs technique for implantation to correct low myopia suggests a diamond knife setting of 68% of local corneal pachymetry,[20] with a lower rate of extrusion in keratoconic corneas (2% to 10%).[6,20] Colin et al.[17] had to explant 2 Intacs segments because of superficial implantation (10% of their series) in keratoconus patients.

Several possibilities may explain our higher rate of extrusion, including shallow tunnel construction because of the surgeon's learning curve and possibly different healing processes in keratoconic corneas compared with normal corneas. We suggest constructing the stromal tunnel with the adjustable diamond knife set at 80% of local corneal thickness to reduce the chance of ring extrusion.

One advantage of this surgery is that it is reversible if the ring has to be removed, and the segments can be reimplanted in a deeper tunnel in most cases 30 days or more after ring extrusion. Furthermore, if the achieved result is not as expected, the originally implanted ring can be exchanged for a thicker one to obtain a stronger effect.[11]

As mentioned, blunt trauma accounted for postoperative complications in 13.7% of our cases. Since the association of keratoconus with atopy is common, many of the patients rubbed their eyes, which may explain the high percentage of blunt trauma. Only 1 eye had a ring-related complication, disciform keratitis; this likely represented an immunologic reaction to the foreign body. The patient had no history of herpetic keratitis or any other form of herpes.

Bacterial keratitis after Intacs implantation is reported to occur in 1% to 20% of cases.[6,20] We had only 1 case of presumed *S epidermidis* keratitis after traumatic ring extrusion. This resolved after ring explantation and vigorous topical and intracorneal antibiotic treatment. The BSCVA returned to the preoperative level.

The FICRS implantation technique is relatively easy for a corneal surgeon, but attention must be paid to some important details including correct tunnel construction, starting at 80% depth of corneal thickness at the location of the radial incision; ring segment centration based on central corneal reflex; and correct selection of ring segment position in the flat corneal meridian.

Our results suggest that FICRS have a promising place in the treatment of keratoconus, especially in patients who are contact-lens intolerant and candidates for PKP for visual improvement. In our series, the procedure was successful in several keratoconus patients who were on the waiting list for PKP. The FICRS procedure is brief extraocular surgery that requires only topical anesthesia and has a low rate of ring rejection. We were able to avoid PKP in 76.5% of the keratoconus eyes during the follow-up.

In conclusion, FICRS implantation has the advantages of being potentially reversible, adjustable, and reasonably safe; it is an inexpensive procedure that avoids or at least delays PKP in keratoconus patients. It should, however, be noted that the long-term stability of the results is unknown. Further clinical and experimental studies with more patients and longer follow-up are needed to improve the safety and predictability and ensure the stability of FICRS results.

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