Long-term outcomes and causes of intrastromal corneal ring segment explantation in a tertiary eye hospital

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Abstract:

PURPOSE: To evaluate the causes and long-term outcomes after intrastromal corneal ring segment (ICRS) explantation in the King Hadeed Eye Specialist Hospital.

METHODS: This was a retrospective cohort study. Two groups were analyzed: Group one, ICRS surgery done in our hospital (n = 41) and group two, surgery done outside but removed in our hospital (n = 29). Causes and postoperative management after ICRS removal were analyzed. For statistical analysis, groups were analyzed into two subgroups of causes of ICRS removal: Visual disturbance versus extrusion/infection/neovascularization (NV) subgroups; and two subgroups of postoperative treatment: Corneal transplant (CT) versus Contact lens (CL)/eyeglasses subgroups.

RESULTS: The most common cause of ICRS removal in group one was visual disturbance (45.2%) while in group two was extrusion (41.2%). CL is the preferable management after explantation. 76% of ICRS removal occurred during the first 4 years. In group 1, there was significant worse preimplantation visual acuity (P = 0.02) in CT subgroup versus CL/eyeglasses. CT subgroup had lower pachymetry of 437.4 μm (P = 0.04) and higher myopia of 8.05 (P = 0.03) than CL/eyeglasses subgroup. For group two, there was a significant improvement in uncorrected visual acuity in visual disturbances subgroup after explantation (P = 0.004). After explantation, visual disturbances subgroup had higher myopia -4.4 than extrusion subgroup -1.15 (P = 0.004).

CONCLUSION: Seventy-six percent of ICRS removal occurred during the first 4 years. High myopia and pachymetry lower than 437 um were associated with visual disturbances and further management with corneal transplantation. High myopia was also associated with visual disturbances in surgeries done outside our hospital.

Keywords: Complications, corneal transplant, intrastromal corneal ring segment implantation, keratoconus

INTRODUCTION

Keratoconus, an ectatic corneal disorder, results from progressive thinning of the corneal stroma and may lead to severely decreased visual acuity in advanced stages of the disease. Treatment modalities include spectacles and contact lenses (CL), and surgical techniques such as intrastromal corneal ring segments (ICRSs), corneal collagen cross-linking, and lamellar or penetrating keratoplasty depending on the stage of keratoconus.[¹]

Implantation of ICRS is a reversible technique designed to achieve orthopedic adjustment by flattening the central cornea curvature while maintaining clarity in the central optical zone and preserving corneal tissue.[²,³] Moreover, it prevents or delays corneal transplant (CT).[⁴] ICRS has been associated with intraoperative and postoperative complications. Intraoperative complications include segment decentration, ICRS asymmetry, inadequate tunnel depth, and dissection with the anterior Bowman layer or anterior chamber perforation.[⁵,⁶] Postoperative complications include segment extrusion,[⁷-⁹] corneal neovascularization (NV),[¹⁰-¹²] infectious keratitis,[¹³] interlamellar white deposits around the ICRS,[⁹,¹¹,¹²,¹⁴] segment migration,[¹,¹²] and corneal melting.[⁶,⁹] Explantation rate varies...
significantly among studies, ranging from 0.98% to 30% with no differences if they were cross-linked or not.[5,8,9,15,16] ICRS insertion in Saudi Arabia represents an excellent potential for a retrospective cohort study. This is due to the high prevalence of KC with contact lens intolerance as a result of baseline discomfort associated with the dry and dusty environment and the high prevalence of vernal keratoconjunctivitis which often precludes contact lens tolerance.[17] The current study aimed to evaluate visual, refractive, and topographic outcomes after ICRS explantation in our hospital. Furthermore, the causes, technique, long-term outcomes were analyzed.

Methods
This was a retrospective cohort study of patients who underwent explantation of ICRS in the largest eye hospital in Saudi Arabia. This study was approved by the institutional review board of the hospital. Two groups were analyzed: Group one, ICRS surgery done in our hospital and group two, surgery done outside but ICRS explanted in our hospital. All the patients who had ICRS explantation between 2002 and 2017 were included in the study. Patients with missing data or <1 year of follow-up were excluded [Table 1].

Data collection
Clinical data related to ICRS implantation and explantation were documented from each patient’s medical record. The following data were collected for each eye: Uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), slit-lamp examination, and corneal topography (PentacamOculusOptikgeräte GmbH, Germany). Readings including flattest keratotomy in the central 3 mm (K1), steepest keratometry in the central 3 mm (K2), mean keratometry (Kmean), astigmatism, and the axis of astigmatism, maximum measured keratometry (Kmax), anterior chamber depth (AC depth), pupil diameter, Krumeich–Amsler classification and classification of the cone based on asymmetry. These data were collected at the following time periods: (1) pre-ICRS implantation (group one), (2) last follow-up post-ICRS implantation, and (3) last follow-up post-ICRS explantation. Date of surgeries, the cause for ICRS removal and the skill level of the surgeon (learning curve or experienced) were documented. Keratoconus management after ICRS removal (eyeglasses, CL, surgery or observation) was recorded.

Table 1: Demographic data in both groups

|                          | Group one | Group two |
|--------------------------|-----------|-----------|
| Number of eyes (n)       | 41        | 29        |
| Gender (%)               | 69% male  | 79% male  |
| Mean age (years)         | 31.78±6.65| 32.38±6.0 |
| Associated VKC (%)       | 21.4% VKC | 27.6% VKC |

No differences regarding gender, age, and presence of VKC were found between groups. VKC: Vernal keratoconjunctivitis

For comparison of clinical data, the following operative parameters were taken into account: (1) Depth of the tunnel: 80% versus 70%–75%, (2) Technique for tunnel creation: Femtosecond laser versus manual, (3) Type of ICRS: Intacs-SK versus myoring/keraring versus Intacs, (4) Insertion technique: Symmetrical versus Asymmetrical, (5) Ring thickness: Less than 400 µs versus 400–500 µs, (6) Causes of explantation: Visual disturbances versus extrusion/infection/NV, and (7) The postoperative data included management after explantation: Contact lens/eyeglasses versus CT.

Data were collected on spreadsheet of Microsoft XL. Then, it was transferred to Statistical Package for Social Sciences (SPSS version 24.0, IBM, Chicago, USA). For comparing the qualitative variables in two groups (implanted at KKESH and those implanted outside KKESH), we calculated the number and percentage. By using two by two tables, we estimated two-sided P value using OpenEpi software of CDC (Atlanta, USA). For quantitative variables, we estimated the mean and standard deviation and estimated two-sided P value using The statistical package for social sciences (SPSS) 27.0 (IBM, Armonk, NY) was used for statistical analysis.

Results
A total of 70 ICRS explantation fulfilled the criteria for the study. Out of this, 41 eyes of 40 patients had ICRS implantation in our hospital and 29 eyes of 29 patients had implantation done outside. Intacs-SK ring was the most common type removed in both groups (group one 66% and group two 93%). Intacs were removed in group one only (24.5%) and one case of myoring and other keraring were removed in each group. No statistical differences were found regarding surgeon, depth of the tunnel, technique for tunnel creation, type of ICRS, insertion technique, and ring thickness.

The causes of ICRS explantation for group one in our study included visual disturbances (45.2%) followed by segment extrusion (38.1%), corneal NV (9.1%), and infectious keratitis (7.1%). Whereas the most common causes of ICRS, removal for group two was extrusion (41.4%), visual disturbances (27.5%), infection (17.2%), and NV (13.7%).

The mean elapsed time between implantation and explantation in group one was 29.6 months (range 1–128 months), being 27.9 months in CL/eyeglasses group versus 34.3 months in CT group. In group 2, the mean elapsed time was 37.3 months (range 2–129 months). 76% of ICRS removal occurred during the first 4 years; 60% of the extrusion happened during the first year and visual disturbances have two peaks, at year 2 and year 6 in both groups.

The CL/eyeglasses were the most common management after explantation in both groups (59.5% and 65.5%, respectively). Surgical treatment was done in 26.8% and 20.7% of patients. The observation was considered in 14.6% and 13.8% of patients [Table 2].

Group one showed statistically significant difference when
the treatment after explantation with CL/eyeglasses subgroup versus CT subgroup was compared. No differences were observed between visual disturbances than extrusion/infection/NV subgroup.

There were significant changes in visual acuity between preimplantation CL/eyeglasses versus CT subgroup in which patients in transplant subgroup has poorer BCVA before implantation ($P=0.02$). UCVA and BCVA improved post-explantation in both subgroups but were not statistically significant. Regarding refraction, mean sphere pre-implantation changed from –8 in CT subgroup to +1.75 postexplantation after CT surgery which was statistically significant different ($P=0.01$). There were also significant differences between CL/eyeglasses versus CT before implantation and after implantation, CT patients had more myopia than other groups ($P=0.03$ and $P=0.001$) [Table 3].

The variation of K mean in CL/eyeglasses preimplantation and postimplantation was statistically significant ($P=0.001$) which changed from 48.8 preimplantation versus 46.9 postimplantation; and 46.9 postimplantation versus 49.6 post-explantation ($P=0.001$). There was no significant difference in K mean between preimplantation and postimplantation in CL/eyeglasses group. For the CT subgroup, the cylinder and the K-mean postimplantation were significantly higher compared with CL/eyeglasses group ($P=0.04$) [Table 4].

The analysis of CT subgroup in group one was statistically significant in pre-implantation apex corneal thickness, CT subgroup was 384.45 µm versus CL/eyeglasses subgroup was 437.4 µm ($P=0.04$) and myopia, CT subgroup was –8.05

### Table 2: Management of Group one and two after intrastromal corneal rings explantation

| Treatment          | Group one (n=41, n (%)) | Group two |  
|--------------------|------------------------|-----------|
|                    | Visual disturbances (n=10, n (%)) | Extrusion/infection/NV (n=19, n (%)) |  
| Contact lens       | 18 (44.9) | 6 (60) | 7 (44.8) |  
| Spectacles         | 6 (14.6) | 0 | 6 (20.7) |  
| Observation        | 6 (14.6) | 1 (10) | 3 (13.8) |  
| Corneal transplant | 11 (26.8) | 3 (30) | 1 (13.8) |  
| Topo-PRK           | 0 | 0 | 2 (6.9) |  

The CL/eyeglasses were the most common management after explantation in both groups (59.5% and 65.5% respectively), followed by surgical treatment (26.8 and 20.7%). NV: Neovascularization, topo PRK: Topographic-guided photorefractive keratectomy, CL: Contact lens vs. CL/eyeglasses subgroup was –3.43 ($P=0.03$). No differences in the other variables were found, however, 7 cases (63.6%) were done during the learning curve of the surgeons. The depth of the tunnel was 70%–75% in 9 cases (81.8%) and Intacs-SK was implanted in 6 cases (54.5%) with a ring thickness of 400–450 um.

For group two (surgery done outside KKESH), UCVA and BCVA improved in the visual disturbance group after explantation but it was only statistically significant for UCVA ($P=0.004$). Postexplantation UCVA of extrusion/infection/NV group was better than preexplantation of visual disturbances group ($P=0.007$). The mean sphere postexplantation of the group two was statistically significant more myopic in visual disturbances group than extrusion/infection/NV group ($P=0.004$), group with visual disturbances had higher myopia (-4.4 D) than the post-extrusion/infection/NV group (-1.1 D). No differences were observed between CL/eyeglasses subgroup versus CT subgroup [Table 5].

### Discussion

The implantation of ICRS is a minimally invasive and reversible surgical procedure that stabilizes the cornea and prevents or delays keratoplasty. The mean interval between implantation and explantation in the study by Ferrer et al. was 7.65 months (range 0.1–82 months). While Alió et al. found that the median time between the initial ICRS implantation and ICRS explantation was 6 months (range 1–84 months). Chhadva et al. found that the average time between ICRS implantation and penetrating keratoplasty was 1.8 ± 1.7 years (range: 0.13–3.5 years). In our study, 76% of ICRS removal occurred during the first 4 years; 60% of the extrusion happened during the 1st year, while visual disturbances have two peaks, at year 2 and year 6 in both the groups. We suggest that the follow-up of ICRS patient should be extended for at least 6 years (94.1% of total removal) after implantation even though 3 extrusions and 1 infection happened during the years 7–11.

Causes of ICRS removal in our study were similar to previous studies. The most common cause of ICRS removal in surgeries done in KKESH was visual disturbance (45.2%) while in surgeries done outside KKESH was extrusion (41.2%). Ferrer et al. detailed patients who underwent ICRS removal due to extrusion (48.2%), refractive failure (37.9%), keratitis (6.8%), and corneal melting and perforation (6.8%). Kanellopoulos
Table 4: Changes in topographic data before and after explantation in Group one

|                      | Preimplantation of ICRS | Postimplantation of ICRS | Postexplantation of ICRS |
|----------------------|--------------------------|--------------------------|--------------------------|
|                      | CL/eyeglasses | Corneal transplant | P | CL/eyeglasses | Corneal transplant | P | CL/eyeglasses | Corneal transplant | P |
| K1 (D)               | 46.5±7.7 | 49.1±8.8 | 0.4 | 44.8±6.7 | 46.9±10 | 0.05 | 47.6±7.3 | 43.6±7.4 | 0.04 |
| K2 (D)               | 50±7.9 | 54±11.3 | 0.8 | 49.2±7.6 | 53±8.6 | 0.05 | 51±7.7 | 46±8.8 | 0.05 |
| Kmean (D)            | 48.8±7.7 | 51±9.0 | 0.4 | 46.9±7.0* | 50±9.2* | 0.04* | 49.6±7.4 | 45.0±7.6 | 0.1 |
| Cylinder (D)         | 4.0±2.0 | 5.1±1.4 | 0.8 | 4.3±2.0* | 6.3±2.4* | 0.04* | 4.5±2.2 | 5.6±3.4 | 0.4 |
| Pachymetry (um)      | 436±65.3 | 334.5±79.5 | 0.04 | 445±77.5 | 414±58.4 | 0.2 | 427±86.9* | 507±68.1* | 0.006* |
| AC depth (mm)        | 3.6±0.38 | 3.6±0.34 | 0.06 | 3.5±0.43 | 3.6±0.4 | 0.7 | 3.4±0.5 | 2.97±0.6 | 0.07 |

K-mean in CL/eyeglasses subgroup preimplantation versus postimplantation and postimplantation versus postexplantation were statistically significant (P<0.001). For the corneal transplant subgroup, the cylinder and the K-mean postimplantation were significantly higher than CL/eyeglasses subgroup (P=0.04). ICRS: Intrastromal corneal rings, CL: Contact lens, AC: Anterior chamber

Table 5: Visual changes before and after explantation in patients complaining of visual disturbance vs extrusion/infection/NV in group two (surgery done outside KKESH)

|                      | Group 2 | Group 2 | P          |
|----------------------|---------|---------|------------|
|                      | Before explantation | After explantation | Extrusion/infection/NV After explantation |
| UCVA                 | 1.13±0.58* | 0.71±0.3* | 0.63±0.3 | 0.004  |
| BCVA                 | 0.47±0.2 | 0.32±0.2 | 0.3±0.2 | 0.007*  |
| Mean sphere (D)      | −2.56±6.23 | −4.4±5.3* | −1.15±2.92* | 0.004* |
| Mean cylinder (D)    | −5.21±1.14 | −4.25±2.22 | −4.07±1.66 |

UCVA improved in visual disturbance subgroup after explantation (P=0.004). Postexplantation UCVA of extrusion/infection/NV subgroup was better than pre-explantation in visual disturbances subgroup (P=0.007). Postexplantation, visual disturbances subgroup was more myopic (−4.4 D) than extrusion/infection/NV group (−1.1 D) (P=0.004). UCVA: Uncorrected visual acuity, BCVA: Best-corrected visual acuity, NV: Neovascularization

et al. reported six cases (30%) of ICRS migration and one (5%) case of corneal melt.[5] Zare et al. reported 10% segment migration and extrusion.[9] Colin reported explantation rate in 12% of eyes implanted with ICRS, due to dissatisfaction with visual symptoms.[13] In a study done by Kwitko and Severo, the segment extrusion rate was 19.6% (10 out of 51 eyes) after Ferrara ring implantation with the manual dissection technique which is comparable to the above-mentioned studies.[20] The femtosecond laser was used in 53.65% of group one in our study and no statistically significant differences were observed. Our results support those in other studies that found no significant differences between methods of tunnel creation.[21-23] However, Monteiro et al. reported a higher rate of intra- and post-operative complications using manual dissection (18.11%) versus femtosecond laser (3.6%).[24] In a systematic review, Batista-Llamas established that the explantation rate is around 0%–1.4%. The explantation rate was greater with Intacs (19%) than Keraring (1%) and related with low quality of vision.[25] In our study, 91.31% of the removed ICRS were Intacs-SK or Intacs, 76% and 15.3%, respectively.

The management of ICRS is infrequently reported. We reported that CL was the most common management after explantation in both groups, no intervention/observation was considered in 10%–14% of patients, and surgical treatment was done in 20%–30% of patients.

Our CT subgroup has poorer BCVA before ICRS implantation (P = 0.02) than visual disturbances subgroup; however, UCVA and BCVA improved after ICRS removal in both subgroups. Ferrer et al. reported that after explantation a significant improvement in UCVA and BCVA was achieved.[4] Asbell et al. found that 3 months after ICRS removal, 21 eyes were within ±1 line or 10 letters of their preoperative best spectacle-corrected visual acuity (BSCVA).[26] Clinch et al. found 41 of 46 patients’ eyes that had undergone ICRS removal had reached BSCVA the 3-month postremoval visit. ICRS removal was not associated with loss of BCVA, induction of astigmatism or myopia. 90% of the eyes returned to within ±2 lines and 76% returned to within ±1 line of preoperative UCVA.[27]

In our study, K-mean in CL/eyeglasses preimplantation and postimplantation was significantly reduced by 3.7% (P = 0.001). These results are comparable to many studies in literature as Kanellopoulos et al. reported a decrease in the mean central corneal curvature by 6.36% from 49.50 ± 1.64 D to 46.35 ± 1.50 D.[1] Furthermore, Zare et al. reported a reduction in the mean central corneal curvature from 49.84 ± 3.58 D to 47.90 ± 3.58 D by a mean of 3.89%.[9] Furthermore, Shabayek and Alio reported a reduction in the mean central corneal curvature from 49.84 ± 3.58 D to 47.90 ± 3.58 D by a mean of 3.89%.[9] Furthermore, Shabayek and Alio reported a reduction in the mean central corneal curvature by 5.46% from 49.23 D to 46.54 D.[21] Alió et al. reported that ICRS placement in keratoconic eyes with low mean keratometry values (53 D) has better outcomes concerning visual acuity, corneal topography, and spherical equivalent (SE), than when used in patients with advanced keratoconus (55 D).[28] Coskunseven et al. stated that the mean central corneal curvature was reduced from 50.63 D preoperatively to 47.56 D postoperatively by a mean of 6.06%.[21] Pinero et al. also reported a reduction in the mean central corneal curvature by 6.4% from 49.8 ± 1.2 D to 46.8 ± 1.2 D by a mean of 4.0%.[29] Kotani et al. reported that ICRS implantation improved visual acuity in keratoconic eyes with mean central corneal curvature from 49.2 ± 2.7 D to 46.2 ± 2.7 D by a mean of 3.0%.[30] Therefore, it is important to consider the impact of ICRS placement on visual acuity and corneal curvature in keratoconic patients.
central corneal curvature from 50.08 ± 5.20 D preoperatively to 45.55 ± 3.31 D postoperatively.\textsuperscript{[29]} Kim et al. had a reduction in the mean central corneal curvature by a mean of 5.88%.\textsuperscript{[30]} While Kwitko and Severo had a more significant reduction in the mean central corneal curvature by 11.64% from 48.76 ± 3.97 D to 43.17 ± 4.79 D.\textsuperscript{[20]}

We found that eyes managed with CL/eyeglasses returned to preoperative baseline visual, refractive, and topographic status 3–6 months after removal (data not shown). There were no differences in Kmean between preimplantation versus postexplantation in CL/eyeglasses subgroup, it means that the effect of implantation is reversible. Chhadva et al. found there was no statistically significant difference in Average K between these time periods ($P = 0.21$), nor between 1-year post-ICRS placement and 1-month post-ICRS removal. They also found that after ICRS removal, there was an improvement in the corneal cylinder between pre-ICRS placement and 1-month post-ICRS removal.\textsuperscript{[19]} Alió et al. demonstrated that ICRS can be safely and easily explanted, with most of the visual, refractive, and topographic features returning to near the preimplantation levels.\textsuperscript{[14]} Chan et al. reported that 33.8% of the eyes had exchange or removal procedures. The preoperative myopia ranged from −0.75 to −4.38 diopters of SE, the cylinder correction was up to 1.00 Diopter. The residual post-explantation SE was ± 1.5 D or less in 92% of eyes and ± 0.5 D or less in 42%.\textsuperscript{[31]} Asbell et al. safely and efficiently extracted the segments of 34 eyes; 95% returned to within ± 1.00 D of their preoperative manifest SE refraction. All eyes had a stable refraction at the 3-month examination after removal and a manifest SE refraction within ± 1.00 D of their 1-month examination after removal. They concluded that ICRS was easily and safely removed, and eyes returned to preoperative refractive status within 3 months.\textsuperscript{[26]}

In the present study, there was a significant decrease of sphere and astigmatism postimplantation in CT subgroup when compared to corresponding preoperative values ($P = 0.01$). There were significant differences between CL/eyeglasses versus CT before implantation and after implantation, CT patients had more myopia than other groups ($P = 0.03$ and $P = 0.001$). Mean sphere pre-implantation changed from 8 diopters in CT group to + 1.75 diopters postexplantation, which was statistically significant different ($P = 0.01$). This hyperopic shift is related with the suturing technique and the preoperative grading of the keratoconus, CT subgroup was implanted in the most advanced keratoconus.

A recent meta-analysis showed that surgery parameters as depth, type of rings, disease’s severity, methods to create the intrastromal tunnel, patient’s gender, and sequence of CXL did not influence the outcomes of ICRS.\textsuperscript{[23]} In our study, the CT subgroup did not have statistically significant differences regarding the surgical parameters except the sphere and corneal thickness. ICRS in CT subgroup was done during the learning curve of the surgeon, who selected candidates with pachymetry thinner than 380 μm ($P = 0.02$), sphere higher than – 8 Diopters ($P = 0.03$); and surgical parameters of tunnel depth of 70%–75% of the corneal thickness and symmetrical Intacs-SK insertion of 400 or 450 μm. Abad et al. found that 7 of 9 patients with anterior stromal necrosis were related Intacs implants of 450 μm.\textsuperscript{[33]} Therefore, pachymetry’s law has to be taking in consideration, the thickness of the ICRS should not exceed half the thickness of the cornea in the thinnest pachymetry reading at 6 mm. Patients with these preoperative parameters are prone to finish in CT and even ICRS can delay the surgery, early CT could recover patients’ vision faster and avoiding ICRS-related complications. Monteiro et al. reported that complications are related with surgeon’s experience, 81.25% of complications were observed during the first 3 years of the learning curve, in eyes with higher preoperatively mean refractive ($P = 0.002$) and topographic cylinder ($P = 0.003$).\textsuperscript{[24]} Siganos et al. described one eye underwent uneventful PKP after ICRS explantation.\textsuperscript{[10]} Chhadva et al. had four patients ended with PKP after intact removal.\textsuperscript{[19]} Furthermore, Samimi et al. reported management with PKP after ICRS explantation in 8 patients due to poor refractive outcomes or insert extrusion.\textsuperscript{[34]} Another study described four eyes that underwent deep anterior lamellar keratoplasty after ICRS removal with good visual outcomes and improved UCVA.\textsuperscript{[35]} Asbell et al. detailed one patient who had photorefractive keratectomy (PRK) performed 10 months after ICRS removal. The procedure improved UDVA (20/16) and manifest refraction (−0.75–0.75 170).\textsuperscript{[36]} In the group 2 of our study, two patients after extrusion were managed with PRK, one of the them improved the vision to 0, 6.

**Conclusion**

The most common cause of ICRS removal in surgeries done in our hospital was visual disturbance (45.2%) while in the surgeries done outside was extrusion (41.2%). 76% of ICRS removal occurred during the first 4 years. 60% of the extrusion happened during the 1st year, while visual disturbances have two peaks, at year 2 and year 6 in both groups. Implantation of ICRS in patients with pachymetry around 380 μm and myopia around-8 were prone to finish in CT and visual disturbances. CL is the preferable management after explantation followed by CT.

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**Conflicts of interest**
There are no conflicts of interest.

**References**

1. Mandathara PS, Stapleton FJ, Wilcoxon MD. Outcome of keratoconus management: Review of the past 20 years’ contemporary treatment modalities. Eye Contact Lens 2017;43:141-54.
2. Alió JL, Shabayek MH, Artola A. Intracorneal ring segments for keratoconus correction: Long-term follow-up. J Cataract Refract Surg 2006;32:978-85.
3. Kymionis GD, Siganos CS, Tsiklis NS, Anastasakis A, Yoo SH,
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1. Al‑Habboubi, et al. Long‑term follow‑up of Intacs in keratoconus. Am J Ophthalmol 2007;143:236‑44.
2. Ferrer C, Alió JL, Montañes AU, Páez‑Santona JJ, del Río MA, de Toledo JA, et al. Causes of intrastromal corneal ring segment explantation: Clinicopathologic correlation analysis. J Cataract Refract Surg 2010;36:970‑7.
3. Kanellopoulos AJ, Lawrence HP, Perry HD, Donnenfeld ED. Modified intracorneal ring segment implantations (INTACS) for the management of moderate to advanced keratoconus: Efficacy and complications. Cornea 2006;25:29‑33.
4. Peña‑García P, Alió JL, Vega‑Estrada A, Barraquer RI. Internal, corneal, and refractive astigmatism as prognostic factors for intrastromal corneal ring segment implantation in mild to moderate keratoconus. J Cataract Refract Surg 2014;40:1633‑44.
5. Alfonso JF, Lisa C, Fernández‑Vega L, Madrid‑Costa D, Montés‑Micó R. Intrastromal corneal ring segment implantation in 219 keratoconic eyes at different stages. Graefes Arch Clin Exp Ophthalmol 2011;249:1705‑12.
6. Nguyen N, Gelles JD, Greenstein SA, Hersh PS. Incidence and associations of intracorneal ring segment explantation. J Cataract Refract Surg 2019;45:153‑8.
7. Zare MA, Hashemi H, Salari MR. Intracorneal ring segment explantation for the management of keratoconus: Safety and efficacy. J Cataract Refract Surg 2007;33:1886‑91.
8. Siganos CS, Kymionis GD, Kartakis N, Theodorakis MA, Astyrakakis N, Palilikaris IG. Management of keratoconus with Intacs. Am J Ophthalmol 2003;135:64‑70.
9. Shetty R, Kurian M, Anand D, Mhaske P, Narayana KM, Shetty BK. Intacs in advanced keratoconus. Cornea 2008;27:1022‑9.
10. Al‑Torbak A, Al‑Amri A, Wagoner MD. Deep corneal neovascularization after implantation with intrastromal corneal ring segments. Am J Ophthalmol 2005;140:926‑7.
11. Clinch TE, Lemp MA, Foulks GN, Schanzlin DJ. Removal of INTACS keratoconic eyes at different stages. Graefes Arch Clin Exp Ophthalmol 2011;249:1705‑12.
12. Al‑Habboubi, et al. Long‑term follow‑up of Intacs in keratoconus. Am J Ophthalmol 2007;143:236‑44.
13. Hersh PS, Issa R, Greenstein SA. Corneal crosslinking and intracorneal ring segments for keratoconus: A randomized study of concurrent versus sequential surgery. J Cataract Refract Surg 2019;45:830‑9.
14. Mahmood MA, Wagoner MD. Penetrating keratoplasty in eyes with keratoconus and vernal keratoconjunctivitis. Cornea 2000;19:468‑70.
15. Alió JL, Piñero DP, Sögütli E, Kubalaglo A. Implantation of new intracorneal ring segments after segment explantation for unsuccessful outcomes in eyes with keratoconus. J Cataract Refract Surg 2010;36:1303‑10.
16. Cihadva P, Yesilmak N, Cabot F, Yoo SH. Intracorneal corneal ring segment explantation in patients with keratoconus: Causes, technique, and outcomes. J Refract Surg 2015;31:392‑7.
17. Kwitko S, Severo NS. Ferrara intracorneal ring segments for keratoconus. J Cataract Refract Surg 2004;30:812‑20.
18. Radu R, Dascălu E, Chitei L, Moișanu C. Femtosecond laser‑assisted intrastromal keratectomy: Clinical results and complications. J Refract Surg 2016;32:755‑7.
19. Ranasinghe P, Li X. Femtosecond laser‑assisted intrastromal keratectomy for keratoconus: A review. J Refract Surg 2019;35:740‑7.
20. Asbell PA, Uçakhan OO, Abbott RL, Assil KA, Burris TE, Durrie DS, et al. Intrastromal corneal ring segments: Reversibility of refractive effect. J Refract Surg 2001;17:25‑31.
21. Clinic TE, Lemp MA, Foulks GN, Schanzlin DJ. Removal of INTACS for myopia. Ophthalmology 2002;109:1441‑6.
22. Alió JL, Artola A, Hassanin A, Haroun H, Galal A. One or 2 Intacs segments for the correction of keratoconus. J Cataract Refract Surg 2005;31:943‑53.
23. Piñero DP, Alió JL. Intracorneal ring segments in ectatic corneal disease — A review. Clin Exp Ophthalmol 2010;38:154‑67.
24. Kim KH, Choi SH, Ahn K, Chung ES, Chung TY. Comparison of refractive changes after deep anterior lamellar keratoplasty and penetrating keratoplasty for keratoconus. Jpn J Ophthalmol 2011;55:93‑7.
25. Chan SM, Khan HN. Reversibility and exchangeability of intrastromal corneal ring segments. J Cataract Refract Surg 2002;28:676‑81.
26. Benoist d’Azy C, Pereira B, Chiambretta F, Dutheil F. Efficacy of different procedures of intra‑corneal ring segment implantation in keratoconus: A systematic review and meta‑analysis. Transl Vis Sci Technol 2019;8:38.
27. Abad JC, Gómez JC, Henriquez MA, Donado JH. Biomicroscopic findings and management of anterior stromal necrosis after long‑term implantation of intacs. Am J Ophthalmol 2020;220:170‑6.
28. Samimi S, Leger F, Touboul D, Colin J. Histopathological findings after long‑term implantation of intrastromal corneal ring segments (ICRS) implantation: A systematic review. J Refract Surg 2019;35:740‑7.
29. Kim KH, Choi SH, Ahn K, Chung ES, Chung TY. Comparison of refractive changes after deep anterior lamellar keratoplasty and penetrating keratoplasty for keratoconus. Jpn J Ophthalmol 2011;55:93‑7.
30. Chan SM, Khan HN. Reversibility and exchangeability of intrastromal corneal ring segments. J Cataract Refract Surg 2002;28:676‑81.