

Two-Year Follow-up of Intracorneal Ring Segments Implantation in Adolescent Patients With Keratoconus

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ABSTRACT

PURPOSE: To evaluate the visual, refractive, topographic, and aberrometric outcomes after intracorneal ring segments (ICRS) implantation in adolescent patients with keratoconus.

METHODS: A retrospective longitudinal study was undertaken with a total of 61 eyes from 47 patients with keratoconus, aged between 13 and 18 years, implanted with a Ferrara-type ICRS. Topography (flattest keratometry, steepest keratometry, and asphericity), uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), refractive error (sphere and cylinder), and aberrometric measurements (spherical aberration and vertical coma) were evaluated before surgery and at 1 month, 6 months, 1 year, and 2 years after surgery.

RESULTS: UDVA exhibited a statistically significant increase at all times from 1 month to 2 years postoperatively ($P < .001$), whereas CDVA showed a statistically significant improvement at 1 month, 6 months, and 2 years ($P < .002$), but dropped in

significance at 1 year postoperatively ($P = .097$). The refractive error analysis showed no variation in statistical significance in the sphere ($P = .712$) after 2 years. The cylinder presented a statistically significant decrease in diopters at all times from preoperatively to 2 years postoperatively ($P < .007$). Steepest keratometry manifested a statistically significant decrease in steepness at all times after surgery ($P < .001$), whereas flattest keratometry lost significance at 1 year ($P = .298$) and 2 years ($P = .053$) postoperatively. There was no statistically significant change in the spherical aberration at any of the measured times. The vertical coma was only significantly different at 2 years postoperatively ($P = .001$).

CONCLUSIONS: ICRS implantation is a safe and effective treatment for improving visual and corneal morphological parameters as shown at 2 years of follow-up in adolescent patients with keratoconus. It is a good option to flatten and regularize the cornea and to temporarily improve the quality of life of young patients and delay the need for keratoplasty.

[J Refract Surg. 20XX;X(X):XX-XX.]

Keratoconus is a progressive corneal ectasia that has recently been associated with inflammatory^{1,2} and oxidative stress³ processes. Progressive corneal thinning and degeneration into a cone-like shape has a significantly negative impact on the visual function of patients and, consequently, on their quality of life.⁴ This eye condition is generally diagnosed between the second and third decade of life with different grades of progression, and its appearance in younger patients usually results in a more aggressive evolution over time.⁵⁻⁸

Current advances in technology have made it possible to detect keratoconus at its primary stages, making early treatment possible by using the available therapeutic options. Depending on the state of the disease and visual loss, management of keratoconus adopts different techniques, including the use of eyeglasses, contact lenses, and surgical procedures, such as corneal cross-linking (CXL), intracorneal ring segments (ICRS) implantation, and corneal transplantation.⁹⁻¹³ The main purposes of the treatments are to slow down

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Submitted: March 2, 2020; Accepted: November 13, 2020

Supported by the Programa Nacional de Cooperación Público-Privada. Subprograma INNPACTO 2015 ECTASIA Project (CP-M).

The authors have no proprietary or financial interest in the materials presented herein.

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doi:10.3928/1081597X-20201123-03

or halt the progression and restore visual function. Although CXL has proven its safety and effectiveness in slowing down the progression in adults and young patients,¹⁴⁻¹⁸ the lower resistance of younger corneas compared to those of adults might affect the outcome.^{19,20} Thus, further investigation is needed to ascertain its long-term sustainability.²¹ Furthermore, some authors question its application as soon as keratoconus is diagnosed without evident signs of progression.²² On the other hand, ICRS are polymethacrylate devices inserted at the mid-peripheral cornea aiming to reduce the mean keratometry and refractive error and to improve the optical aberrations of the cornea.^{10,23} These devices are a safe and reversible therapeutic option for visual rehabilitation in adults.²⁴ However, there is still insufficient evidence about the effectiveness of ICRS for controlling progression and it is still under debate. Moreover, there are only a few studies reporting data on young patients.²⁵⁻²⁷ Preserving the visual function in this segment of the population is a matter of crucial importance because visual impairment could also translate into a negative impact on their psychological and social development.²⁸

For all of these reasons, this retrospective study assessed the outcomes of the implantation of ICRS by evaluating the changes and stability over time of different parameters regarding refraction, topography, aberrometry, and visual quality in patients younger than 18 years with keratoconus.

PATIENTS AND METHODS

This is a retrospective longitudinal study that was performed at the FISABIO-Oftalmología Médica and Aviñó Peris Eye Clinic, both located in Valencia, Spain. A total of 47 patients with keratoconus, aged between 13 and 18 years, were recruited. Ferrara-type ICRS were implanted in one eye in 33 patients and in both eyes in the rest of the patients, giving a total number of 61 eyes. The study followed the ethical principles of the Declaration of Helsinki and the eye clinics provided the corresponding ethics approval. All patients were properly informed about their inclusion in the study. They all signed an informed consent after receiving verbal and written explanations about the details and nature of the study and the possible consequences of the surgery.

INCLUSION AND EXCLUSION CRITERIA

Inclusion criteria were patients younger than 18 years with a transparent central cornea, contact lens intolerance, and a mesopic pupil size of 5.5 mm or less. Exclusion criteria included ocular media opacity, antecedents of corneal dystrophy or trauma, active

systemic or ocular diseases, impaired eyelid anatomy and function, participation in another clinical study, and not attending all of the visits of the protocol defined in the study.

SURGICAL TECHNIQUE

All surgical interventions were performed by the same expert surgeons (CP-M and MH-D) using topical anesthesia. In all cases, incisions were made on the steepest meridian according to the topographic map. A 60-kHz IntraLase femtosecond laser (IntraLase Corporation) was used to create the corneal tunnels where the ring segments were to be implanted. The marking of the center of the pupil was performed first, followed by the application of the vacuum suction ring. The disposable glass lens of the laser system was then made to flatten the cornea to fixate the eye and help maintain a precise distance from the laser head to the focal point. Then, a continuous circular stromal tunnel was created at approximately 80% of corneal depth. Once this procedure was complete, the corneal incision was hydrated with intrastromal cefuroxime. Topical tobramycin-dexamethasone eye drops (Tobradex; Alcon Laboratories, Inc) were used postoperatively every 6 hours for 1 week. Topical lubricant eye drops containing sodium hyaluronate 0.1% and which were preservative-free (Hyabak; Thea Labs) were applied every 6 hours for 1 month.

The selection of the number, arc length, and thickness of the segments was made using a nomogram according to the protocol for ICRS insertion published earlier by Alfonso et al.²⁵ All eyes were implanted with a KeraRing segment (Mediphacos). KeraRing segments are ring segments made of polymethylmethacrylate with inner and outer diameters of 6 and 7.2 mm, respectively. The segments have a triangular transverse section, a base with a width of 800 μ m, and a thickness ranging from 150 to 350 μ m.

MEASUREMENTS AND STATISTICAL ANALYSIS

The measurements were evaluated after a complete ophthalmologic examination, including refractive error (sphere and cylinder), uncorrected (UDVA) and corrected (CDVA) visual acuity expressed in logMAR units, and corneal parameters such as anterior keratometry, asphericity, or higher order corneal aberrations (fourth-order spherical aberration (Z^4_0) and third-order vertical coma (Z^3_{-1}). These corneal parameters were obtained by means of the Pentacam HR (Oculus Optikgeräte GmbH) clinical device.

All measurements were assessed with a maximum follow-up of 2 years and data were recorded before baseline surgery time and at 1 month, 6 months, 1

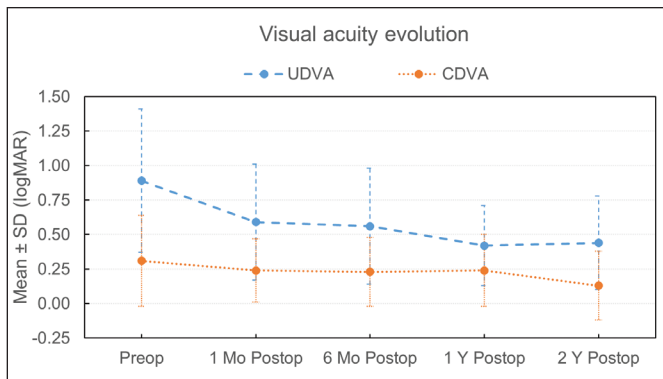


Figure 1. Uncorrected (UDVA) and corrected (CDVA) visual acuity before and evolution after intracorneal ring segments implantation up to 2 years of follow-up. SD = standard deviation

year, and 2 years postoperatively. The only exception is asphericity, the data for which are only available up to 1 year of follow-up. Because the ratio of eyes to patients was relatively low (1.3 eyes on average per patient), the observations were considered as independent. Specifically, the 61 eyes were treated as though they belonged to 61 different patients.

The statistical analysis was performed with a commercially available software package (SPSS for Mac, Version 22.0; IBM Corporation). The descriptive analysis includes parameters such as the average, standard deviation, and range values for each dependent variable. As to the inferential analysis, the Brunner-Langer non-parametric longitudinal data model was used to evaluate the changes over time. This model is justified by the longitudinal design of the data and the moderate sample size, as a non-parametric alternative to the repeated-measures analysis of variance. In this regard, the so-called analysis of variance-type statistic was used to detect statistically significant differences. The significance level was set to a P value of less than .05. The follow-up has not been completed for the 61 patients. The descriptive analysis presents information about all available patients at each time. The inferential statistical analysis is restricted, in each variable, to the number of cases with information at all time points.

Normality of data samples was evaluated using the Kolmogorov-Smirnov test. When parametric analysis was possible, the paired t test was used for comparisons between consecutive visits, whereas the Wilcoxon ranked-sum test was applied to assess the significance of such differences when parametric analysis was not possible.

RESULTS

The patients were 33 males (70.2%) and 14 females (29.8) with a mean age of 16 ± 1.3 years (range: 13 to 18

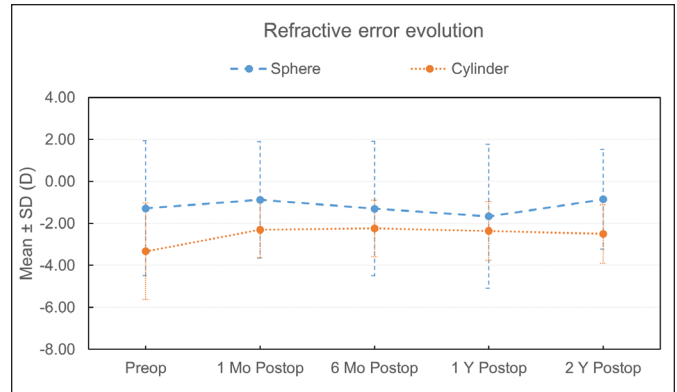


Figure 2. Refractive parameters before and evolution after intracorneal ring segments implantation up to 2 years of follow-up. SD = standard deviation; D = diopters

years). In total, 61 eyes were evaluated, of which 22 had stage 1 (36.1%), 30 had stage 2 (49.2%), 6 had stage 3 (9.8%), and 3 had stage 4 (end-stage) keratoconus (4.9%) according to the Amsler-Krumeich classification. The ICRS were implanted using the femtosecond laser procedure in 57 eyes (93.4%), whereas the mechanical technique was used in 4 eyes (6.6%). There were no complications associated with ICRS implantation except for five extrusions, one of which was reinserted.

Table A (available in the online version of this article) provides the preoperative and postoperative values at the different time points, showing the evolution of the UDVA and CDVA. The UDVA experienced a significant increase after 1 month with respect to the preoperative values ($P < .001$). This significant increase was maintained after 2 years, but there was no significant improvement between postoperative time points. The CDVA also showed significant differences at 1 month ($P = .002$), but the average gain was less marked than that of the UDVA. In the case of the CDVA, it was possible to confirm a significant improvement after 2 years postoperatively ($P < .001$), although 1 year after the procedure the changes were not found to be significant. **Figure 1** compares the evolution of UDVA to CDVA.

Table B (available in the online version of this article) lists all of the values corresponding to sphere and cylinder. There were no relevant changes before or after the surgery in the distribution of sphere values, and this value should be considered stable throughout the follow-up because there was no relevant variation over time. On the other hand, the cylinder value decreased significantly after surgery ($P < .001$), and remained stable during the 2-year follow-up with no significant changes over time after the procedure. **Figure 2** provides the evolution of the corresponding descriptive parameters.

Table C (available in the online version of this article) lists the values of the flattest (Kmin) and steepest

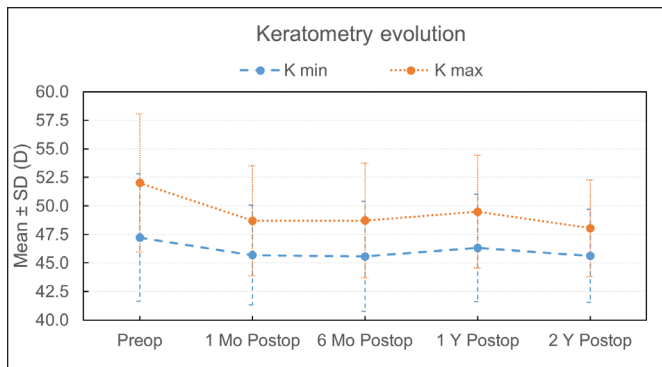


Figure 3. Keratometry values before and evolution after intracorneal ring segments implantation up to 2 years of follow-up. Kmin = flattest keratometry; Kmax = steepest keratometry; SD = standard deviation; D = diopters

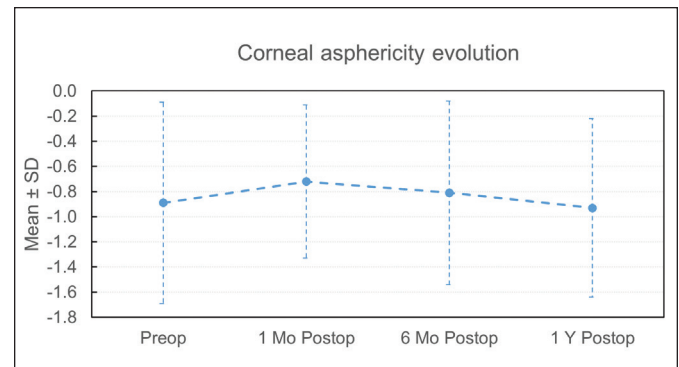


Figure 4. Corneal asphericity before and evolution after intracorneal ring segments (ICRS) implantation up to 1 year of follow-up. SD = standard deviation

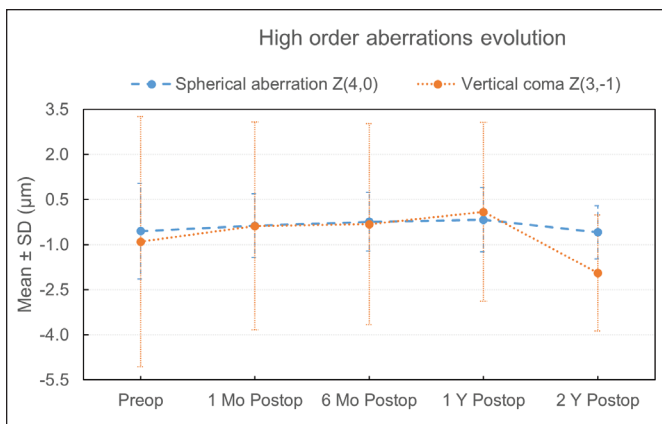


Figure 5. Spherical aberration and vertical coma Zernike coefficients before and evolution after intracorneal ring segments (ICRS) implantation up to 2 years of follow-up. SD = standard deviation

(Kmax) meridians, together with corneal asphericity. There was a significant reduction in Kmin and asphericity compared to preoperative values 1 and 6 months after the intervention. This was not the case after 1 year, when the parameters showed no statistical differences concerning the preoperative measures. Nevertheless, at 2 years, the Kmin remained at an average value similar to that at 6 months, the *P* value being close to the limit of significance. Regarding Kmax, a significant decrease was observed after surgery and it was stable throughout the observation period (*P* < .001). **Figures 3-4** show the evolution of these measures.

Table D (available in the online version of this article) represents the values of higher optical aberrations, such as the fourth-order spherical aberration and third-order vertical coma. Despite the observable change in the spherical aberration at the descriptive level (**Figure 5**), there was not enough evidence to interpret it as reliable because there were no statistical differences before or after the procedure or throughout

the follow-up period. As to the vertical coma, this parameter seemed to decrease significantly after 2 years of follow-up.

DISCUSSION

In this study, changes were analyzed over 2 years after implantation of ICRS in patients younger than 18 years with keratoconus to determine the effectiveness of this treatment in restoring visual function and stabilizing the progression of ectasia. Currently, there is no single indicator that determines the evolution of keratoconus, but it is usually assessed through the observation of different parameters that affect vision and corneal morphology. For this reason, this study analyzes the evolution of different visual, refractive, and morphological parameters that are compared with their baseline values before surgery, to determine the variations over time.

The intervention generated some significant changes in the study variables. The analysis, in general, yielded evident changes after 1 month postoperatively that lost strength over time. This can be explained, in part, by the reduction in the sample, because not all of the patients completed the follow-up period, or by the remission of the values. Importantly, both the UDVA and CDVA of the patients improved significantly after the intervention. The improvement was noticeable at the 1-month visit and it was maintained at later time points, although it was less manifest for the correction measure and there was a significant regression. Refractive astigmatism decreased significantly after the intervention and this change was maintained up to the final visit. Nevertheless, neither the sphere nor the spherical equivalent showed significant variations throughout the observation period. As to the corneal morphological parameters, Kmin and Kmax decreased significantly between baseline and 1 month, and this change was stable up to 6 months. After 1 year, only

Kmax remained significantly different with respect to baseline measures. The asphericity values led to the same conclusions. The decrease was significant in the early postoperative period. At first, the cornea became less prolate up to 6 months after surgery, but there was a regression after 1 year comparable to preoperative values. Furthermore, keratoconus causes irregularities on the corneal surface that lead to higher order aberrations, which are reduced by ICRS as they regularize the corneal surface. However, despite the decreasing tendency of spherical aberration and vertical coma throughout the whole follow-up in the descriptive analysis (**Figure 5**), it was not strong enough to make a statistically significant difference with respect to preoperative values. This reduction, although not statistically significant, may have had a positive clinical impact on the visual outcomes of the patients and may partially explain the improvement in their visual acuity, together with the notable reduction of refractive astigmatism.

To date, only a few studies have been published on the outcomes of implantation of ICRS in children and adolescents whose results are mainly in line with those of our study within the 6 months after intervention; however, some differences were observed, especially in terms of stability at the end. The most recent study included patients between 10 and 18 years of age, which reported satisfactory results after the implantation of Ferrara-type ICRS in terms of visual rehabilitation over a period of up to 60 months.²⁵ Specifically, their UDVA and CDVA improved significantly at 6 months and up to 74.5% of the eyes gained lines of CDVA. The refractive, morphological, and aberrometric measurements were significantly lower and were maintained until the end of the period. Additionally, a study that recruited children between 8 and 16 years of age reported similar values with improvement after implantation and stability until the end of the follow-up period, which in this case was 2 years.²⁶ Another recent study evaluated young patients, aged between 10 and 18 years, with progressive keratoconus for a period of more than 5 years.²⁷ Six months after the intervention, the decimal UDVA improved significantly from 0.07 ± 0.09 to 0.25 ± 0.15 , whereas the CDVA varied from 0.34 ± 0.21 to 0.54 ± 0.17 . During the follow-up, the values remained practically constant, although the keratometric parameters showed a tendency to regression, but did not reach preoperative values. Another study included young patients, but they were older than our sample (aged 19 to 30 years old).²⁹ Their results after ICRS implantation in a period of 5 years revealed that both UDVA and CDVA improved significantly after the intervention up to 6

months later in patients with progressive keratoconus, but at 5 years (maximum follow-up period) both values worsened again. Similarly to our study, regression was also observed in keratometric values, whereas higher order aberrations showed a reduction that was not statistically significant. It should be taken into account that, although in our case some parameters, such as UDVA and Kmax, remained significant until the end of the period, the maximum follow-up time was only 2 years.

Moreover, some published studies including grown adults have also reported satisfactory results with ICRS^{30,31} whereas some others have suggested that they are not a sufficient treatment by themselves for preventing progression and that their effect is only temporary.¹⁸ This discrepancy may be partially due to the fact that the rate of progression of the disease was not often considered before the intervention. In the special case of the youngest segment of the population, this can be difficult to determine because sometimes the diagnosis is made late.^{15,32} It is expected that in keratoconus with a lower rate of progression, there will be greater stability after ICRS implantation than for those patients with a faster active progression,³³ which is precisely what occurs in younger patients.²⁸ In addition, risk factors such as eye rubbing, which is more frequent in children,³⁴ contribute to a more pronounced progression and possible extrusions after ICRS implantation, thereby losing the benefits of the treatment. In the case of our study, young patients were old enough (at least 13 years) to comply with the indications of medical staff and eye rubbing after the intervention was practically non-existent, so it was not a factor that influenced our results.

Different outcomes between young patients and adults can also be explained by the natural corneal stiffening that occurs with aging.^{6,18} In an effort to strengthen the corneal structure, CXL has become an important surgical treatment and numerous studies have concluded it is a safe and effective therapy to halt the progression of the disease.³⁵⁻³⁷ Some studies have even shown that pediatric patients seem to benefit more from this technique than adults in terms of visual improvement.³⁸ Nevertheless, most of the good results have been demonstrated in a relatively short time after surgery. After 3 years, the effects have been reported to diminish and they might not be as long-lasting as in adults, which is why a more exhaustive monitoring of these patients is needed.

In view of our results and those of previously published studies, it seems acceptable to consider ICRS implantation as a good option to flatten and regularize the cornea, although there is no consensus in de-

termining its effectiveness in arresting disease progression. They can be specially considered in cases of advanced keratoconus to temporarily improve the quality of life of young patients and delay the need for keratoplasty. In other words, there is a significant chance that ICRS implantation yields an impermanent result in young people. Therefore, CXL should be employed either before, during, or after treatment. In this sense, recent surgical techniques try to combine ICRS implantation and CXL to obtain the benefits of both of them.³⁹ The application of these techniques is rather new and requires more research to be able to determine its effectiveness in delaying the evolution of the disease for as long as possible. Moreover, it is not known what part of the changes in the parameters is explained by the progression of the disease and what part by the surgical response and its remission after treatment. Thus, it is necessary to conduct further research on the biomechanical properties of the cornea in different age groups and to study how they vary after surgery over time.

AUTHOR CONTRIBUTIONS

Study concept and design (CP-M, MH-D, MJR-R, EA-M, SM-M); data collection (CP-M, MJR-R, EA-M, SM-M); analysis and interpretation of data (CP-M, MH-D, MJR-R, EA-M, SM-M, DM-R); writing the manuscript (CP-M, MH-D, DM-R); critical revision of the manuscript (CP-M, MJR-R, EA-M, SM-M); statistical expertise (CP-M); administrative, technical, or material support (CP-M); supervision (CP-M, MH-D, MJR-R, EA-M, SM-M, DM-R)

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TABLE A
Visual Acuity Outcomes Before and After ICRS Implantation^a

Parameter	UDVA (logMAR)	CDVA (logMAR)
Preoperative	0.89 ± 0.52 [0.10, 1.85] (33)	0.31 ± 0.33 [0.00, 1.85] (60)
Postoperative		
1 month	0.59 ± 0.42 [0.00, 1.85] (52)	0.24 ± 0.26 [0.00, 1.30] (57)
6 months	0.56 ± 0.42 [0.00, 1.85] (32)	0.23 ± 0.32 [0.00, 1.85] (48)
1 year	0.42 ± 0.29 [0.05, 0.82] (13)	0.24 ± 0.26 [0.00, 1.00] (29)
2 years	0.44 ± 0.34 [0.02, 1.30] (18)	0.13 ± 0.21 [0.00, 0.70] (15)
P values		
Preoperative to 1 month	< .001	.002
Preoperative to 6 months	< .001	.002
Preoperative to 1 year	< .001	.097
Preoperative to 2 years	< .001	< .001
1 month to 6 months	.514	.131
1 month to 1 year	.163	.722
1 month to 2 years	.096	< .001
6 months to 1 year	.296	.378
6 months to 2 years	.204	.012
1 year to 2 years	.984	.002

ICRS = intracorneal ring segments; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity

^aValues are presented as mean ± standard deviation [range] (median).

TABLE B
Refractive Error Outcomes Before and After ICRS Implantation^a

Parameter	Sphere (D)	Cylinder (D)	Spherical Equivalent (D)
Preoperative	-1.28 ± 3.22 [-8.00, 6.00] (60)	-3.33 ± 2.30 [-7.50, 9.00] (58)	-2.88 ± 3.03 [-10.00, 3.00] (60)
Postoperative			
1 month	-0.88 ± 2.77 [-10.00, 6.00] (55)	-2.30 ± 1.34 [-6.00, 0.00] (55)	-2.11 ± 2.99 [-12.00, 5.50] (53)
6 months	-1.30 ± 3.20 [-10.00, 4.00] (47)	-2.24 ± 1.35 [-5.00, 0.00] (46)	-2.51 ± 3.12 [-11.00, 1.75] (45)
1 year	-1.66 ± 3.44 [-10.00, 4.00] (29)	-2.36 ± 1.40 [-4.75, 0.00] (28)	-2.72 ± 3.14 [-11.00, 1.75] (28)
2 years	-0.85 ± 2.38 [-4.50, -3.50] (18)	-2.50 ± 1.40 [-5.00, 0.00] (17)	–
P values			
Preoperative to 1 month	.746	< .001	.019
Preoperative to 6 months	.879	< .001	.224
Preoperative to 1 year	.528	< .001	.647
Preoperative to 2 years	.712	.007	–
1 month to 6 months	.676	.674	.548
1 month to 1 year	.351	.815	.405
1 month to 2 years	.970	.593	–
6 months to 1 year	.450	.513	.668
6 months to 2 years	.838	.469	–
1 year to 2 years	.489	.738	–

ICRS = intracorneal ring segments; D = diopters

^aValues are presented as mean ± standard deviation [range] (median).

TABLE C
Keratometry and Asphericity Outcomes Before and After ICRS Implantation^a

Parameter	Kmin	Kmax	Asphericity
Preoperative	47.22 ± 5.58 [38.80, 73.80] [61]	52.02 ± 6.05 [42.40, 76.80] [61]	-0.89 ± 0.80 [-2.29, 1.23] [61]
Postoperative			
1 month	45.69 ± 4.38 [37.50, 59.30] [57]	48.71 ± 4.83 [41.10, 63.70] [57]	-0.72 ± 0.61 [-2.13, 0.88] [57]
6 months	45.58 ± 4.80 [38.10, 62.40] [50]	48.72 ± 5.03 [41.80, 63.70] [50]	-0.81 ± 0.73 [-3.66, 0.22] [50]
1 year	46.32 ± 4.70 [37.00, 60.70] [29]	49.49 ± 4.94 [42.10, 64.80] [29]	-0.93 ± 0.71 [-3.45, 0.13] [29]
2 years	45.63 ± 4.09 [41.00, 57.30] [18]	48.05 ± 4.24 [41.40, 60.00] [18]	–
P values			
Preoperative to 1 month	< .001	< .001	.002
Preoperative to 6 months	< .001	< .001	.011
Preoperative to 1 year	.298	.001	.389
Preoperative to 2 years	.053	< .001	–
1 month to 6 months	.499	.988	.845
1 month to 1 year	.251	.173	.127
1 month to 2 years	.737	.433	–
6 months to 1 year	.066	.141	.166
6 months to 2 years	.937	.586	–
1 year to 2 years	.315	.174	–

ICRS = intracorneal ring segments; Kmin = flattest keratometry; Kmax = steepest keratometry

^aValues are presented as mean ± standard deviation [range] (median).

TABLE D
Outcomes of Higher Order Aberrations (Spherical Aberration and Vertical Coma) Before and After ICRS Implantation

Parameter	Spherical Aberration Z ⁴ ₀ (μm)	Vertical Coma Z ³ ₋₁ (μm)
Preoperative	-0.55 ± 1.59 [-8.53, 2.17] [59]	-0.90 ± 4.16 [-12.67, 6.00] [51]
Postoperative		
1 month	-0.37 ± 1.06 [-2.79, 1.85] [58]	-0.38 ± 3.46 [-9.51, 7.93] [49]
6 months	-0.24 ± 0.98 [-2.63, 1.63] [50]	-0.32 ± 3.35 [-9.78, 7.14] [45]
1 year	-0.17 ± 1.07 [-2.38, 1.94] [29]	0.09 ± 2.97 [-7.80, 5.89] [26]
2 years	-0.59 ± 0.89 [-2.05, 1.84] [18]	-1.94 ± 1.93 [-6.96, 1.01] [18]
P values		
Preoperative to 1 month	.966	.879
Preoperative to 6 months	.190	.812
Preoperative to 1 year	.308	.479
Preoperative to 2 years	.327	.001
1 month to 6 months	.128	.853
1 month to 1 year	.315	.671
1 month to 2 years	.437	.001
6 months to 1 year	.899	.706
6 months to 2 years	.073	.001
1 year to 2 years	.058	.003

ICRS = intracorneal ring segments; Kmin = flattest keratometry; Kmax = steepest keratometry

^aValues are presented as mean ± standard deviation [range] (median).