Intrastromal Corneal Ring Segment Implantation by Femtosecond Laser for the Correction of Residual Astigmatism After Penetrating Keratoplasty

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Purpose: To evaluate the safety and efficacy of intracorneal ring segments (ICRSs) aided by femtosecond (FS) laser for the correction of residual astigmatism after penetrating keratoplasty (PKP).

Methods: This retrospective noncomparative study comprised 14 eyes of 14 patients with high astigmatism after PKP who had ICRS implantation by femtosecond laser. The study evaluated uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), refractive astigmatism, and corneal maximum curvature.

Results: The CDVA postoperatively improved after 3 months ($P < 0.001$) and 6 months ($P < 0.001$) compared with CDVA preoperatively. The CDVA at 3 months was similar to that at 6 months ($P > 0.999$) as well as the UDVA ($P = 0.276$). The preoperative astigmatism was higher than that after surgery ($P = 0.001$). The preoperative maximum curvature was higher than that of the postoperative maximum curvature ($P < 0.001$).

Conclusions: The implantation of ICRSs using the femtosecond laser for residual astigmatism post-PKP was safe and showed satisfactory results. It reduced refractive astigmatism and maximum corneal curvature and improved UDVA and CDVA.

Key Words: intracorneal ring segment, penetrating keratoplasty, femtosecond laser, keratoconus

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Refractive errors, such as residual astigmatism after penetrating keratoplasty (PKP), are frequent and remain a challenge for surgeons of the anterior segment. The occurrence of a high degree of astigmatism in patients after PKP surgery has different causes. These include eccentric and irregular trephination of host cornea, intrinsic astigmatism or irregular-shaped cut of the donor tissue, donor diameter, suture tension, host peripheral thinning or ectasia, bad positioning of tissues, and the depth and type of suture.[1,2]

Residual astigmatism may be corrected with glasses or rigid contact lenses for irregular astigmatisms. When optical methods fail to achieve satisfactory visual rehabilitation, surgical procedures may be necessary, such as selective removal of suture, relaxing incisions, transepithelial photorefractive keratectomy (PRK),[3] astigmatic keratotomy,[4,5] wedge resection,[1,6–8] PRK,[9] and laser in situ keratomileusis (LASIK).[10,11] Besides the difficulty these techniques present, they do not always produce predictable results.[1,3–12]

Implants of intracorneal segments are being used to correct corneal ectasia with a clear cornea, and the results are reported to be good. It is a safe procedure that does not affect the central visual axis of the cornea and has been used to treat keratoconus, pellucid marginal degeneration, post-LASIK ectasia, and post-PRK ectasia.[13–15]

In this study, we evaluated the safety and efficacy of the intracorneal ring segment (ICRS) implantation for correcting residual astigmatism post-PKP using femtosecond (FS) laser. To our knowledge, this is the first study to evaluate ICRS implantation in a group of patients post-PKP using FS laser.

MATERIALS AND METHODS

This retrospective noncomparative study comprised 14 eyes of 14 patients with the diagnosis of keratoconus who were submitted to PKP and followed up in the postoperatory with a high degree of astigmatism after suture removal. All patients were informed appropriately about the procedure and signed informed consent statements. This study was approved by the department's ethics committee.

The patients had contact lens intolerance and had ICRS (Kerarings) implantation by FS laser (IntraLase, 60 kHz). The patients were submitted to slit-lamp examination, manifest refraction, and corneal tomography with the Orbscan II (Bausch & Lomb). The uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), refractive astigmatism, maximum corneal curvature, and pachymetry were evaluated before surgery and 1, 3, and 6 months after surgery. Visual acuity was evaluated with a Snellen chart and converted to logarithm of the minimal angle of resolution (logMAR) values.

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Surgical Technique

The surgical procedure was performed under sterile conditions and topical anesthesia. The reading of the Purkinje reflex was done with patients lying down and under the microscope. Corneal thickness was measured using Orbscan pachymetry. Tunnel depth was set at 80% of the thinnest corneal thickness on the tunnel location in the FS laser.

The incision site varied according to the site of the steepest topographic axis provided by the Orbscan. Two ring segments (Kerarings; Mediphacos) were implanted according to the distribution of the ectatic area on the corneal surface. The thickness of the segments was decided according to the distribution of the ectatic area and the spherical equivalent, following the nomogram suggested by the manufacturer. Intrastromal tunnels were created using FS laser. IntraLase parameters were 5.0 mm internal diameter and 5.8 mm external diameter. The entry cut thickness was 1 μm (at the steepest topographic axis), and the ring energy used for channel creation and the entry cut energy was 1.3.

After creating incisions and tunnels with the IntraLase, we used the Grupenmacher delaminator to open the incisions for implanting the segments. At the end of the procedure, therapeutic contact lenses were placed and fourth-generation fluoroquinolone was installed. Postoperatively, antibiotic–steroid eye drops were taken 4 times a day for 14 days. The patients were instructed to avoid rubbing the eye and to use preservative-free artificial tears frequently.

On the first postoperative day, a slit-lamp biomicroscopic examination was performed. Corneal wound healing and migration of the segment were evaluated. The paired Student *t* test was used for statistical analysis. It was performed using SPSS for Windows software (version 15.0; SPSS, Inc, IBM, Chicago, IL). A P value <0.05 was considered statistically significant.

RESULTS

Ten women and 4 men with an average age of 37.4 years were included in the study. Average time of transplant before the intracorneal implant was 9.5 years. Two patients were followed only until the third postoperative month. Table 1 shows all patient findings.

The UDVA after 3 months was higher than the preoperative values in 92.8% of cases. At 6 months after surgery, there was an improvement in UDVA over the preoperative values in 85.7% of cases. For the UDVA, in only 1 case, the visual acuity at 6 months was higher than the visual acuity at 3 months. UDVA was maintained to preimplantation level in 2 eyes (14.29%), 4 eyes (28.57%) experienced a UDVA gain of up to 3 lines, 5 eyes (35.71%) gained up to 4 to 6 lines, and 3 eyes (21.43%) gained up to 7 lines (Fig. 1). In the evaluation of CDVA after 3 months, there was improvement in 85.7% of cases. In relation to the visual acuity presented at 3 months, in 78.6% of cases, the CDVA was the same at 6 months postoperatively. All eyes gained improved CDVA after 6 months compared with preoperative levels. Seven eyes (50%) improved 1 up to 3 lines, 3 eyes (21.43%) improved 4 up to 6 lines, and 4 eyes (28.57%) improved up to 7 lines (Fig. 2).

The results of inferential statistical tests showed that the UDVA preoperatively was statistically lower compared with 3 months ($P = 0.001$) and 6 months ($P = 0.002$) postoperatively. The UDVA at 3 months was statistically equal to 6 months ($P = 0.276$). The CDVA preoperatively was statistically lower compared with 3 months ($P < 0.001$) and 6 months ($P < 0.001$) postoperatively. The CDVA at 3 months was statistically equal to 6 months ($P > 0.999$). The preoperative astigmatism was statistically higher than the postoperative astigmatism ($P = 0.001$; Fig. 3). The preoperative maximum curvature was statistically higher than the postoperative maximum curvature ($P < 0.001$; Fig. 4).

There were no complications related to the procedure. One patient was not satisfied with his visual acuity after the procedure. His UDVA before surgery was counting fingers, CDVA was 20/200, and the maximum topographic curvature was 50.60 diopters (D). After ICRS implantation, his UDVA was 20/100 and did not improve when wearing glasses. His visual acuity wearing contact lenses was 20/40, but the

TABLE 1. Preoperative and Postoperative Data

	Preoperative				Postoperative			
Patient	UDVA	CDVA	Kmax	Refraction	UDVA	CDVA	Kmax	Refraction
1	1.00	0.60	49.60	−0.50 −6.00 × 165	0.69	0.17	46.80	Plano −5.00 × 180
2	2.00	1.00	52.50	−3.00 −9.00 × 80	1.00	0.69	49.00	−2.75 −6.00 × 80
3	2.00	1.00	55.50	−5.50 −5.50 × 180	0.69	0.47	48.68	−9.75 −0.75 × 150
4	2.00	1.00	52.80	−6.75 −8.75 × 165	0.47	0.30	51.30	Plano −1.00 × 30
5	2.00	1.30	50.50	−9.00 −6.00 × 160	0.47	0.39	48.70	−9.00 −1.00 × 105
6	2.00	0.69	46.40	−14.00 −5.00 × 180	1.00	0.47	44.70	−16.00 −3.00 × 155
7	2.00	1.30	50.40	Plano −9.00 × 170	2.00	0.00	48.50	+6.50 −6.00 × 130
8	2.00	0.60	58.20	−3.00 −4.50 × 50	1.00	0.00	55.60	−0.25 −1.75 × 60
9	0.69	0.47	44.90	+0.50 −5.00 × 160	0.39	0.30	48.40	−0.50 −1.50 × 150
10	2.00	0.69	51.00	Plano −6.00 × 160	1.30	1.00	53.50	+4.75 −5.25 × 05
11	0.69	0.30	51.00	−3.00 −5.00 × 180	0.69	0.47	49.10	−2.75 −5.00 × 180
12	2.00	1.00	57.30	−11.00 −4.25 × 90	1.00	0.30	53.70	−11.25 −1.50 × 65
13	1.00	1.00	50.60	−3.25 −5.25 × 30	0.69	0.69	46.90	−6.00 −3.75 × 130
14	0.60	0.47	58.70	+1.00 −6.00 × 100	0.17	0.00	50.80	+1.50 −6.00 × 100

Kmax, maximum curvature.

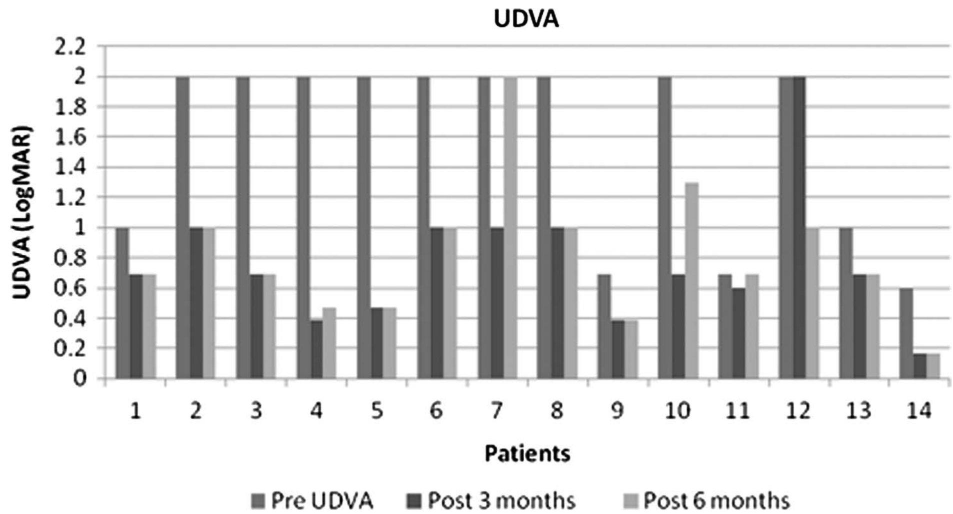

FIGURE 1. Evolution of UDVA preoperatively, and 3 and 6 months postoperatively. LogMAR, logarithm of the minimal angle of resolution.

patient did not become adapted to them; thus, he was indicated for a new PKP.

DISCUSSION

Cornea posttransplant astigmatism is a challenge for surgeons, and many studies have been done with the aim of minimizing this complication.[1,3–11] In our study, we found that ICRS implantation is a safe option to reduce residual astigmatism after PKP. A comparison of the pre- and postoperative visual acuity showed that an improvement both with and without correction was obtained in most cases. There was significant improvement in both CDVA and UDVA at 3 months postoperatively. In relation to the topographic parameters, we found statistically significant reduction in the astigmatism value between the preoperative and postoperative periods. The topographic curvature was also significantly reduced.

Rigid gas-permeable contact lenses are a good choice for these patients, but sometimes they are not well tolerated. Correction of these refractory errors can be effectively achieved with procedures such as relaxing incisions, compressive sutures, wedge resections, and astigmatic keratotomy; however, these procedures have a high incidence of recurrence of astigmatism and low predictability.[2] In our study, we found stable refractive outcomes after 3 months. At 6 months postoperatively, there was no significant difference in relation to the 3-month outcomes. This becomes important when we have to develop and provide refractive solutions for improvement in visual performance even after the implants. Therefore, we suggest that it is better to wait 3 months (time responsible for the biomechanical or bioelastic balance) before prescribing a new contact lens or glasses.

The study by Villalobos et al[15] comprised eyes with high post-PKP. astigmatism in patients who had ICRS implantation by mechanical stromal dissection and found that ICRS implantation provided stable refractive results after 29 months. Their results also showed an improvement in CDVA and corneal topography.

Excimer laser PRK and LASIK are also alternatives to treat astigmatism after PKP; however, these procedures have limitations, such as corneal graft thickness, their restriction to

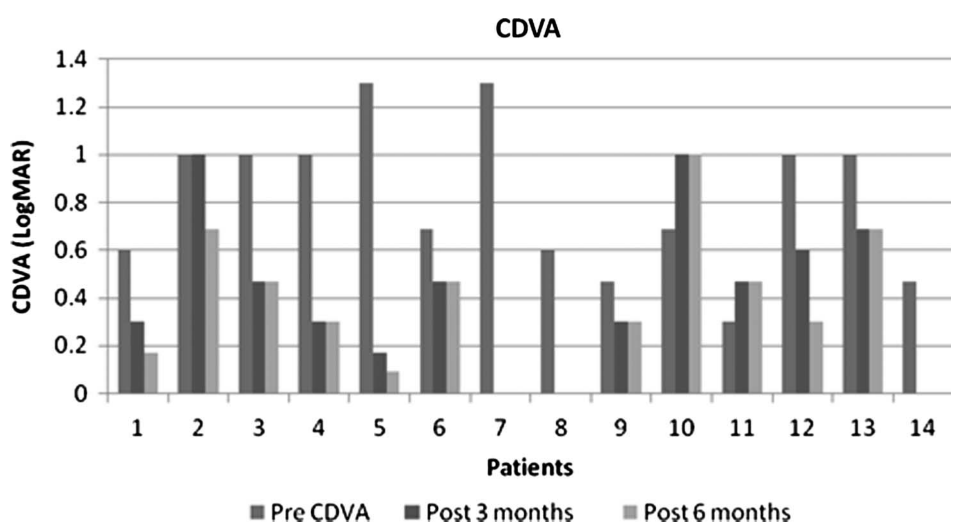

FIGURE 2. Evolution of CDVA preoperatively, and 3 and 6 months postoperatively.

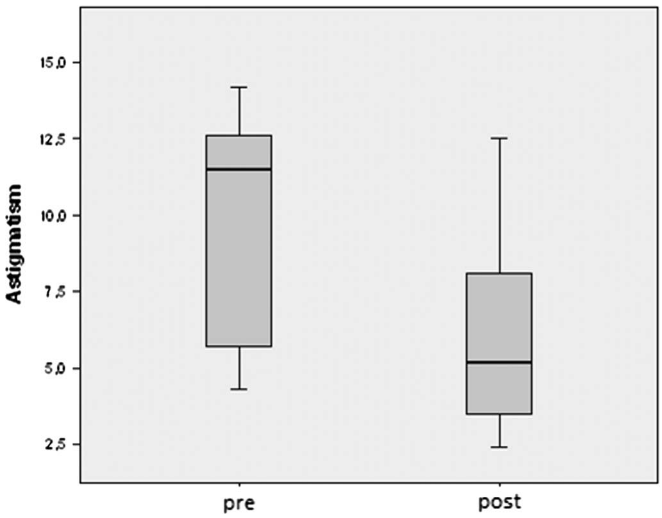

FIGURE 3. Box plot of astigmatism during the preoperative and 3-month postoperative periods.

regular symmetrical astigmatism, the amount of refractive error may limit the efficacy of the procedure, and they present high regression rates. Additionally, there is the risk of graft failure, the risk of haze with the PRK technique, and the complications related with flap in the LASIK technique, such as epithelial ingrowth, flap dislocation, and dry eye.[8–12] ICRS implantation has several advantages compared with other techniques to treat residual astigmatism after PKP. It does not affect the central visual axis of the cornea, which minimizes the risk for opacification caused by scarring in the visual zone; and it is a reversible procedure, so if the refractive outcomes are unsatisfactory, the ICRS can be explanted and after 3 months replaced with a thinner or thicker ring.

ICRS implantation with FS laser is an effective method for correcting keratoconus.[16] The use of FS laser to create the tunnels that were used to implant the segments was predictable and uneventful. FS laser rather than the manual procedure in our cases of postoperative PKP was preferred to avoid possible damage to the interface by the traction generated by the dissectors used during surgery in the manual technique. In addition, other complications mostly associated with the mechanical technique of tunnel creation include epithelial defects, incisional gapping, anterior and posterior perforations, shallow or asymmetric placement, decentration, stromal thinning, corneal melting, and corneal stromal edema around the incision and channel from surgical manipulation.[15]

Other reported complications include infectious keratitis, sterile keratitis, chronic pain, corneal anterior stromal necrosis, white stromal deposits (with no alteration in optical performance), and stromal channel neovascularization.[15] In our study, there were no complications related to the technique.

Coskunseven et al[17] presented a case report of an ICRS implantation with the FS laser in a postkeratoplasty patient with recurrent keratoconus with satisfactory visual acuity recovery and no complications.

The limitation of our study is that we used a slit-scanning technique (Orbscan) instead of reflection topography. We chose this technique because we needed a simultaneous pachymetry map because tunnel depth was set based on the thinnest corneal thickness on the tunnel location in the FS laser. We also used Orbscan in the postoperatory to use the same technology after ICRS implantation to compare data.

In this study, we report an improvement in UDVA, CDVA, refractive astigmatism, and maximum corneal curvature after Keraring implantation. Despite these satisfactory results, we observed that several patients maintained high manifest refraction, which is not well correlated with their good visual acuity (Table 1), suggesting that for these patients, the improvement in visual acuity was attributable to a topographic change induced by the ICRS, which allowed better vision despite the refraction. ICRS implantation for correction of high residual astigmatism post-PKP with FS laser is a safe technique that provides visual recovery and improves refractive and topographic outcomes, thus offering a good choice for these patients.

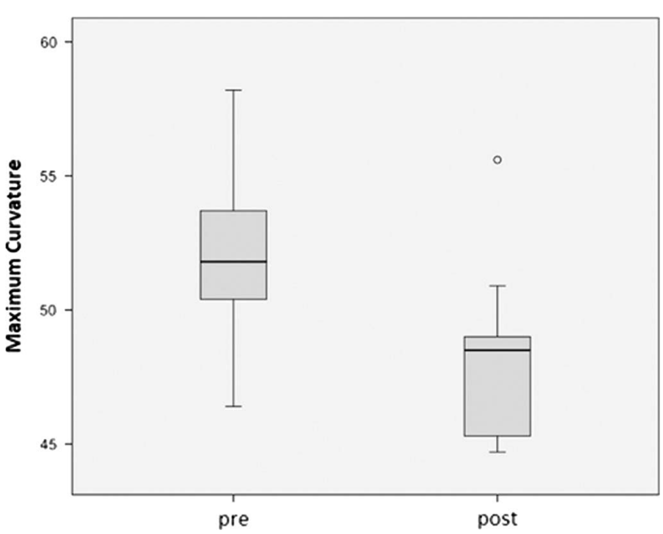

FIGURE 4. Box plot of maximum curvature during the preoperative and 3-month postoperative periods.

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