The Potential Impact of Cone Eccentricity on Visual Outcomes in Inferior and Central Keratoconus Patients following Keraring Implantation: A Pilot Preliminary Study

1Iraklis Vastardis, 2Aye Khine, 3Mohamed Elalfy, 4Samer Hamada, 5Georgios Perdikakis, 6Markus Kohlhaas
7Zisis Gatzioufas

ABSTRACT

Aim: To evaluate possible correlation of cone eccentricity and visual acuity in inferior and central keratoconus patients following Keraring implantation for keratoconus.

Materials and methods: A total of 19 eyes from an equal number of patients were analyzed in this preliminary pilot retrospective study. Two groups were formed, group I for inferior (n = 11) and group II for central keratoconus (n = 9). Uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), keratometric readings, central corneal thickness, maximum keratometric distance from corneal apex (DKmax), and corneal thinnest point from corneal apex (DTh) were evaluated preoperatively and 6 months after the Keraring implantation. The DKmax and DTh were measured and from corneal apex to evaluate the eccentricity of the cone.

Results: The CDVA and refractive cylinder reduction improved at 6 months postoperatively in both groups (t-test, p = 0.002, p = 0.005 and p = 0.12 respectively). There was a high correlation between CDVA and corneal astigmatic reduction (p = 0.0283, correlation coefficient r = −0.7) and a negative relation in regression analysis (p = 0.0240, y = 0.2616 + −0.1354 × + 0.03750 ×, coefficient r = −0.7) and a negative relation in regression analysis (p = 0.0283, correlation coefficient r = −0.7) and a negative relation in regression analysis (p = 0.0283, correlation coefficient r = −0.7) and a negative relation in regression analysis (p = 0.0283, correlation coefficient r = −0.7) and a negative relation in regression analysis (p = 0.0283, correlation coefficient r = −0.7). There was no correlation between them in t-test at 6 months.

Conclusion: Both groups profited from a Keraring implantation in terms of CDVA, but a relation between corneal astigmatic reduction and CDVA after Keraring implantation at 6 months was found only in patients with central keratoconus.

Clinical significance: This finding suggests that a visual acuity improvement in keratoconus patients is not only topographic and keratometric-related but also higher order aberration reduction-dependent. Bigger prospective studies that also evaluate corneal aberration reduction findings are needed to support our results.

Keywords: Eccentricity, Kerarings, Keratoconus.


Source of support: Nil

Conflict of interest: None

INTRODUCTION

Intracorneal ring segments (ICRS) are polymethylmethacrylate implants that are inserted into the 5 mm zone of the cornea, resulting in a geometrical alteration of its properties and enhancing its refractive output and visual outcomes.

These implants were first proposed by Burris\(^3\) as surgical solution for moderate refractive myopia, but were employed in keratoconic patients by Collin et al\(^2\), showing that ICRS is a viable and promising surgical option in terms of topographical regularity that results in increased uncorrected visual acuity among other findings.

Many models of ICRS in relation to thickness, diameter, and shape are available nowadays and used to regulate corneal geometry in order to restore visual acuity in patients with keratoconus. They are inserted between the corneal stromal fibers, where a remodeling arc-shortening effect is induced, which flattens the 3 to 5 mm zone and restores corneal symmetry.\(^3\)

Some theoretical models have shown that the flattening effect is directly proportional to the thickness of the ICRS and inversely proportional to the corneal diameter, suggesting that the thicker the segment and the smaller the diameter in the cornea where the device is implanted, the higher the flattening effect will be achieved.\(^4\) These models apply only to normal corneas.
where an orthogonal pattern of the collagen fibers is found, but in an abnormal cornea with keratoconus, with an abnormal disposition of fibers, the response of the segments is unpredictable. Barraquer also proposed “Thickness law” stating that when tissue is added to the periphery of the cornea or tissue is removed from the center, a flattening of the cornea will be achieved and vice versa, that could explain also the flattening effect of ICRS. Many studies have provided positive results after ICRS implantation in keratoconus patients in relation to improved keratometry, spherical equivalent, higher order aberrations, and refractive cylinder changes, but also in UDVA, CDVA respectively. Overall, ICRS present good long-term results and their beneficial effect even after ICRS explanation is well documented. Complications following ICRS implantation include infections, displacement or migration, extrusion, corneal scarring, and vascularization. Their implantation was initially managed manually where a calibrated diamond blade was used to create a corneal pocket at approximately 70% of the corneal thickness after fixation of the eye with a suction ring placed around the limbus. The pocket of the corneal stroma is elongated with two semicircular dissectors that advance in the deep stroma in a clockwise and counter-clockwise movement, making space between the corneal lamellas where ICRS will be inserted. With the advent of femtosecond laser technology, simplifying the procedure, the mechanical method was less favored. Several nomograms have surfaced over the years but the most widespread ones used are those proposed by the main manufacturers of ICRS. These nomograms are custom fit according to topographic findings of each patient’s corneal characteristics, which consider indications and contraindications, thus providing safety and efficacy of this surgical procedure.

However, we are of the opinion that despite all this information available and all the technology surrounding modern corneal surgery nowadays, we have yet to determine a clear prognostic preoperative factor that could guarantee success in relation to visual outcomes after ICRS implantation in patients with keratoconus. This preliminary retrospective pilot study tries to highlight any difference in terms of visual acuity rehabilitation when the inferior keratoconus and central keratoconus are compared and if the eccentricity plays a role regarding topographic findings in such patients after ICRS implantation.

**MATERIALS AND METHODS**

This was a retrospective, preliminary pilot study. Our study included 19 patients (Table 1) with stable keratoconus who underwent unilateral Keraring (Mediphacos, Belo Horizontale, Brazil) implantation with the use of a femtosecond laser (LDV Z6; Ziemer, Port, Switzerland). The patients were divided into two groups, group I for inferior keratoconus and group II for central keratoconus. All patients had keratoconus stage 2 or 3 according to the Amsler-Krumeich classification. Corneal topography was evaluated using a Scheimpflug camera (Pentacam; Oculus Optikgeräte, Wetzlar, Germany). Keratoconus was diagnosed by corneal topography and corneal elevation mapping, and evaluated by Scheimpflug imaging (Pentacam).

None of the eyes included had undergone corneal cross-linking or refractive surgery and they all had stable keratoconus prior to surgery. Inclusion and exclusion criteria are seen in Table 2. A complete ophthalmic examination was performed preoperatively and postoperatively, including UDVA, CDVA, manifest refraction, spherical equivalent, keratometry readings (in diopters [D]), central corneal thickness (µm), maximum keratometric distance from corneal apex (DKmax), and thinnest point distance from corneal apex (DTh).

The DKmax and DTh were used as topographic landmarks of the cone eccentricity and have been calculated

### Table 1: Demographic summary table of both groups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
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<tbody>
<tr>
<td><strong>Demographic data of the study group I</strong></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>11</td>
</tr>
<tr>
<td>Age median and standard deviation</td>
<td>43 ± 6.66 years</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>8:3</td>
</tr>
<tr>
<td>Right eye:left eye ratio</td>
<td>4:7</td>
</tr>
<tr>
<td>Inferior Keratoconus stage 2:stage 3 ratio</td>
<td>5:6</td>
</tr>
<tr>
<td><strong>Demographic data of the study group II</strong></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>9</td>
</tr>
<tr>
<td>Age median and standard deviation</td>
<td>43 ± 10.6 years</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>6:3</td>
</tr>
<tr>
<td>Right eye:left eye ratio</td>
<td>4:5</td>
</tr>
<tr>
<td>Central keratoconus stage 2:stage 3 ratio</td>
<td>3:6</td>
</tr>
</tbody>
</table>

### Table 2: Exclusion and inclusion criteria

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
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<tbody>
<tr>
<td>Age over 21 years</td>
<td>Age less than 21 years</td>
</tr>
<tr>
<td>Signed informed consent</td>
<td>Prior refractive surgery or cross-linking</td>
</tr>
<tr>
<td>CDVA&lt;0.2 LogMar or 0.63 Snellen</td>
<td>Corneal scarring</td>
</tr>
<tr>
<td>Corneal thickness &gt;400 µm in the area of ICRS implantation</td>
<td>Ocular surface anomalies, e.g., dry eye disease</td>
</tr>
<tr>
<td>Keratoconus inferior and central</td>
<td>Other ocular pathology</td>
</tr>
<tr>
<td>Rigid form contact lens intolerance</td>
<td>Pregnancy</td>
</tr>
<tr>
<td>Postoperative</td>
<td>Chloramphenicol 0.5%/2 weeks</td>
</tr>
<tr>
<td>Topical regimen</td>
<td>Fluorometholone 0.1%/4 weeks</td>
</tr>
</tbody>
</table>
with the aid of the Pentacam-derived x and y values for Kmax and thinnest point respectively, using the Pythagorean theorem: Distance from the center = Visual acuity was measured using Snellen and then converted to logMAR for statistical analysis.

The appropriate ring segment for every single procedure was selected individually for each patient according to the manufacturer provided nomogram and precalculated parameters. Keratoconus shape (nipple, bow tie, or oval), corneal asymmetry, astigmatic values, and manifest refraction are integrated in this nomogram and taken into consideration prior to implantation.

The first ring segment was inserted directly in flat axis of the cone. Its diameter was 5 mm and the thickness varied from 150 to 300 µm. The tunnels were created with femtosecond laser. Topical anesthesia was applied (proparacaine hydrochloride 0.5%) and the apex of the conus was marked with ink preoperatively. After applanation of the cornea with a suction ring, the precalculated incision (2.7 mm) and corneal tunnels (1.3 mm width and 80% depth) were created in the 5-mm zone. The length of the tunnel was created to match the preselected implants.

The implantation of the ring segments was facilitated with special forceps. Follow-up took place at postoperative 1 day, 1 week, and 1, 3, and 6 months. All patients provided their written consent prior to surgery and the tenets of the Declaration of Helsinki were fully respected. The local institutional review board committee approved this study. Statistical analysis was performed using MedCalc software (version 15; MedCalc, Oostende, Belgium).

Parametric or nonparametric tests were used according to distribution. A p-value of less than 0.05 was considered statistically significant. Results of 19 patients and 19 eyes were divided in two groups and analyzed in this preliminary retrospective pilot study to investigate any difference in terms of visual acuity rehabilitation when the inferior keratoconus and central keratoconus are compared and if the eccentricity plays a role regarding topographic findings in such patients after ICRS implantation. The UDVA improved although the comparison of the means was not found statistically important.

Graph 1 clearly demonstrates that cumulative visual acuity improved in both groups, with group I reaching a 55% of 0.7 LogMar (0.2 Snellen) or better and 36% a
0.2 LogMar (0.63 Snellen). In group II, 67% reached a 0.7 LogMar (0.2 Snellen) or better and 11% a 0.3 LogMar (0.5 Snellen). The CDVA and refractive cylinder reduction improved at 6 months postoperatively and the difference was statistically important in both groups (t-test, \( p = 0.002, \ p < 0.0001 \) and \( p = 0.0007, \ p = 0.0017 \) respectively). Cumulative visual outcomes of CDVA are presented in Graph 2.

However, spherical equivalent and keratometric findings (K1, K2, and Kmax) favored clearly group II but not group I (t-test, \( p = 0.002, \ p = 0.005 \) and \( p = 0.85, \ p = 0.12 \) respectively). There was a high correlation between CDVA and corneal astigmatic reduction (\( p = 0.0283 \), Correlation coefficient \( r = -0.7 \)) and a negative relation in regression analysis \( (p = 0.0240, \ y = 0.2616 + -0.1354 \times + 0.03750 \times 2, \ \text{Coefficient of determination} \ R^2 = 0.7115) \) for the central keratoconus but not for the inferior one (Graph 3).

There was no correlation between the topography landmarks DKmax or DTh and visual outcomes and no

Graphs 2A to C: Group I: cumulative comparison results—UDVA baseline and 6 months. Group II: Cumulative comparison results—UDVA baseline and 6 months. Group I vs II: Cumulative comparison results—UDVA at 6 months.
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statistical difference was found between them in t-test at 6 months. Table 3 summarizes all results found.

Over the years, many studies clearly demonstrated that the flattening effect of ICRS is directly proportional to the thickness of the implanted segment and inversely proportional to the corneal diameter at the implantation site.23,24 Surgical management of keratoconus with ICRS has proven to be a minimally invasive and reliable surgical option that provides very good visual outcomes in terms of UDVA, CDVA, spherical equivalent, and keratometry amelioration but also improvement of rigid form contact lenses toleration.8,9,13,23,25,26 This small retrospective preliminary pilot study was set out to evaluate possible correlation of cone eccentricity and visual acuity in patients with inferior or central keratoconus who underwent unilaterally ICRS implantation and also to attempt to establish a clear preoperative prognostic factor that could guarantee postoperative success in visual outcomes.

Preoperative prognostic factors have been identified from surgeons to be associated with the visual outcomes after ICRS implantation like poor preoperative visual acuity and alignment of the refractive and keratometric axes (angle <15°) favoring optimal visual outcomes9,27 but also that significant visual improvement is less likely in advanced keratoconus, a fact that has been linked to low predictability of the keratometric and visual outcomes.25,28 Regarding our topographic landmarks, no correlation was found between DKmax or DTh and visual outcomes and no statistical difference was found between them in t-test at 6 months postoperatively, so that a direct prognostic factor in relation with these two parameters was not established.

We did, however, notice a great difference in spherical equivalent and keratometric findings (K1, K2, and Kmax), a high correlation between CDVA and corneal astigmatic reduction and a negative relation in regression analysis postoperative that favored clearly central keratoconus group over the inferior one. We know that central cones seems to respond better in various surgical treatments and that its location appears to affect visual acuity with better results for cones within a central 2-mm zone.29,30 Considering that CDVA and refractive cylinder reduction improved at 6 months postoperatively and the difference was statistically important in both groups, we assume that such an improvement in keratoconus patients is not only topographic and keratometric-related but also higher order aberration reduction-dependent. Other studies have clearly established a link between increase of visual acuity and improvement of the aberrometric profile, mainly in reduction of coma, as a result of corneal geometry and symmetry improvement after ICRS implantation.9,13 Recently, Gatzioufas et al31 demonstrated an improvement of keratometric readings, but also reduction of coma after ICRS implantation leading to UDVA and CDVA improvement.

**DISCUSSION**

Over the years, many studies clearly demonstrated that the flattening effect of ICRS is directly proportional to the thickness of the implanted segment and inversely proportional to the corneal diameter at the implantation site.23,24

Surgical management of keratoconus with ICRS has proven to be a minimally invasive and reliable surgical option that provides very good visual outcomes in terms of UDVA, CDVA, spherical equivalent, and keratometry amelioration but also improvement of rigid form contact lenses toleration.8,9,13,23,25,26 This small retrospective preliminary pilot study was set out to evaluate possible correlation of cone eccentricity and visual acuity in patients with inferior or central keratoconus who underwent unilaterally ICRS implantation and also to attempt to establish a clear preoperative prognostic factor that could guarantee postoperative success in visual outcomes.

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**CONCLUSION**

Although in this small study both groups profited from ICRS implantation, we can conclude that the central cone group showed, despite the sheer small number of eyes, better results in terms of corneal astigmatic reduction and CDVA relation.
Still in relation to our limitations in this study, we feel that larger prospective studies are required to investigate further the effect of conus location on ICRS outcomes and validate these results.

CLINICAL SIGNIFICANCE

The ICRS implantation improves visual acuity in both central and inferior keratoconus. Presumably, visual acuity improvement in keratoconus patients who underwent Keraring implantation is not only topographic and keratometric-related but also higher order aberration reduction-dependent.

REFERENCES

