intracorneal ring segments (ICRS) are small polymethylmethacrylate devices implanted into the cornea to alter its geometry in a manner that will enhance its refractive properties and thereby improve visual acuity. The concept of ICRS implantation was first proposed by Burris in 1978 for treatment of myopia. Colin et al. introduced the use of ICRS implantation for the management of keratoconus in 2000. Since then, many different types of ICRS with variable thickness, geometry, and diameter have been developed and used for restoring visual acuity in patients with keratoconus. Their implantation was initially managed mechanically, but femtosecond laser-assisted implantation has been gradually replacing the conventional mechanical technique.

The mechanism of action in ICRS is simple. They act as spacer elements between the collagen fibers of the corneal stroma and induce an arc-shortening effect, resulting in flattening of the central corneal area. It has been shown that the flattening effect is directly proportional to the thickness of the ICRS and inversely proportional to the corneal diameter. Several studies documented that implantation of ICRS decreases keratometric readings, spherical equivalent, and cylinder, reduces higher order aberrations, and improves uncorrected (UDVA) and corrected distance visual (CDVA) acuity in patients with keratoconus. Moreover, ICRS present good long-term results and their beneficial effect is preserved to some extent after ICRS explanation. The complication rate is relatively low and mostly includes postoperative complications such as infection, ICRS displacement/migration, ICRS extrusion, corneal scarring, and corneal vascularization.

ABSTRACT

PURPOSE: To investigate the potential impact of cone eccentricity on visual outcomes after Keraring (Mediphacos, Belo Horizonte, Brazil) implantation for keratoconus.

METHODS: Nineteen eyes from 19 patients with keratoconus who underwent femtosecond laser-assisted Keraring implantation for keratoconus were included in this retrospective study. Uncorrected visual acuity (UDVA), corrected visual acuity (CDVA), keratometric readings, central corneal thickness, maximum keratometric distance from corneal apex (DKmax), corneal thinnest point from corneal apex (DTh), and coma were evaluated preoperatively and 6 months after the Keraring implantation. DKmax and DTh were used as metrics reflecting the eccentricity of the cone.

RESULTS: UDVA, CDVA, keratometric readings, and coma improved at 6 months postoperatively. However, there was no correlation between DKmax or DTh and visual outcomes at 6 months postoperatively.

CONCLUSIONS: The data did not show any impact of the cone eccentricity on visual outcomes after Keraring implantation for keratoconus at 6 months postoperatively.

Effect of Conus Eccentricity on Visual Outcomes After Intracorneal Ring Segments Implantation in Keratoconus

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Submitted: April 4, 2017; Accepted: December 20, 2017

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

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doi:10.3928/1081597X-20180115-02
There are now implantation nomograms, most of them offered by the ICRS manufacturers, indicating the appropriate ring segment characteristics for each individual case and suggesting in a customized manner the most suitable parameters for ICRS implantation. There are also certain indications and contraindications regarding the patient selection to maximize the safety and efficacy of the treatment.\textsuperscript{10,15} However, there are still many gray zones in the preoperative assessment. Which prognostic factors could influence the clinical outcome or predict the success/failure rate of this treatment method?

The aim of our study was to investigate whether the eccentricity of the cone correlates with the final visual outcome after ICRS implantation for stable keratoconus.

PATIENTS AND METHODS

This was a retrospective, interventional cohort study. Our study included 19 patients with stable keratoconus who underwent unilateral Keraring (Mediphacos, Belo Horizontale, Brazil) implantation with the use of a femtosecond laser (LDV Z6; Ziemer, Port, Switzerland). All patients had keratoconus stage 2 or 3 according to the Amsler–Krumelich classification. None of the treated eyes had undergone corneal cross-linking in the past and they all had stable keratoconus for a period longer than 12 months prior to ICRS implantation. Patients were enrolled in the study dataset on the basis of the following criteria: age older than 21 years, contact lens intolerance, CDVA of less than 0.2 logMAR (0.63 Snellen), and corneal thickness more than 400 microns in the area of ICRS implantation, plus absence of central corneal scars, ocular surface disease, allergic eye disease, previous ocular surgery, or any other ocular pathology except for keratoconus. Pregnant or breast-feeding women were excluded from the study cohort.

A complete ophthalmic examination was performed preoperatively and postoperatively, including UDVA, CDVA, manifest refraction, spherical equivalent (SE), keratometry (K) readings (in diopters [D]), central corneal thickness (µm), maximum keratometric distance from corneal apex (DKmax), and thinnest point distance from corneal apex (DTh). Corneal topography was evaluated using the Scheimpflug camera (Pentacam; Oculus Optikgeräte, Wetzlar, Germany). Diagnosis of keratoconus was facilitated by corneal topography and corneal elevation mapping, as evaluated by Scheimpflug imaging (Pentacam). Visual acuity was measured using Snellen notation and then converted to logMAR for statistical analysis. DKmax and DTh were used as indicators of the cone eccentricity and have been calculated with the aid of the Pentacam-

derived x and y values for Kmax and thinnest point, respectively, using the Pythagorean theorem:

\[
\text{Distance from the center} = \sqrt{x^2 + y^2}
\]

The standard nomogram of the ICRS provided by the manufacturers was used for selection of the appropriate ring segment in each individual case and calculation of the implantation parameters. This nomogram is based on the keratoconus pattern morphology (nipple, bow-tie, or oval cone), the keratoconus pattern symmetry (percentage of ectatic area located on one side of the steep corneal meridian), and the amount of corneal astigmatism and manifest refraction (manifest sphere diopters). All patients had one ring segment implanted in the flat meridian adjacent to the cone, with a diameter of 5 mm and variable thickness between 150 and 300 µm. Intrastromal tunnels were created using a femtosecond laser. After topical anesthesia with proparacaine hydrochloride 0.5%, the corneal apex was marked with ink under the surgical microscope (OPMI Lumera 700; Carl Zeiss AG, Jena, Germany). A suction ring of 9.5 mm was applied and, after applanation, a corneal tunnel of 1.3 mm width was created with the femtosecond laser in the 5-mm zone and 80% corneal depth, as well as a single, radial, 2.7-mm corneal incision at the tunnel starting point. The corneal tunnel length was equal to the ring segment arc length plus 10°. Ring segments were inserted into the tunnel with the aid of special forceps. Postoperatively, patients were prescribed chloramphenicol 0.5% eye drops for 2 weeks and fluorometholone 0.1% eye drops for 4 weeks. Scheduled follow-up was at postoperative 1 day, 1 week, and 1, 3, and 6 months.

All patients provided their written consent prior to ICRS implantation and the tenets of the Declaration of Helsinki were fully respected. The local institutional review board committee approved this study.

STATISTICAL ANALYSIS

Normality of the data distribution was tested using the Shapiro–Wilk test and parametric and non-parametric tests were applied accordingly. All results are presented as mean ± standard deviation. A P value of less than .05 was considered statistically significant. All statistical analyses were performed using MedCalc software (version 15; MedCalc, Ostend, Belgium).

RESULTS

Nineteen eyes (10 left and 9 right eyes) of 19 patients were included. Demographic data are presented in Table 1.
Significant improvement was observed in all parameters examined in this study between baseline and follow-up at 6 months apart from the CCT and the DTh. All results are summarized in Table 2.

No correlation was observed between preoperative DKmax and UDVA improvement (Pearson’s correlation coefficient, \( r = 0.2739; P = .2565 \)) or preoperative DKmax and CDVA improvement (Pearson’s correlation coefficient, \( r = 0.08701; P = .7232 \)). Moreover, no correlation was observed between DKmax difference and UDVA improvement (Pearson’s correlation coefficient, \( r = 0.1958; P = .4217 \)) or DKmax difference and CDVA improvement (Pearson’s correlation coefficient, \( r = 0.02175; P = .9296 \)). Similarly, no correlation was observed between preoperative DTh and UDVA improvement (Pearson’s correlation coefficient, \( r = 0.3142; P = .1902 \)) or preoperative DTh and CDVA improvement (Pearson’s correlation coefficient, \( r = 0.4083; P = .0827 \)).

**DISCUSSION**

There is evidence 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.\(^{16}\) The efficacy of ICRS in managing keratoconus has been well documented. ICRS reduce spherical equivalent and keratometric readings, higher order aberrations, and particularly coma, thereby improving UDVA and CDVA.\(^{6,7,12,17}\) The increase in visual acuity is attributed to the improvement of the aberrometric profile and mainly to the reduction of coma, as a result of the regularized corneal geometry after ICRS implantation.\(^{7,12}\) Moreover, ICRS implantation significantly improved the contact lens tolerance, as shown by numerous studies.\(^{17-19}\)

Several factors have been identified to be associated with the visual outcomes after ICRS implantation. Vega-Estrada et al.\(^{7}\) reported that poor preoperative visual acuity is a good prognostic factor for significant visual improvement, whereas Alió et al.\(^{20}\) suggested that significant visual improvement is less likely in advanced keratoconus (stage 4). Advanced keratoconus has also been linked to low predictability of the

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### TABLE 1

**Demographic Data of the Study Group**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>19</td>
</tr>
<tr>
<td>Mean age ± standard deviation (y)</td>
<td>38.3 ± 6.4</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>12:7</td>
</tr>
<tr>
<td>Right eye:left eye ratio</td>
<td>9:10</td>
</tr>
<tr>
<td>Keratoconus stage 2:stage 3 ratio</td>
<td>7:12</td>
</tr>
<tr>
<td>Contact lens intolerance</td>
<td>11</td>
</tr>
<tr>
<td>Previous corneal cross-linking</td>
<td>0</td>
</tr>
</tbody>
</table>

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### TABLE 2

**Summary of the Visual, Refractive, and Corneal Topographic and Tomographic Outcomes After ICRS Implantation in Patients With Keratoconus**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDVA (logMAR)</td>
<td>1.19 ± 0.41</td>
<td>0.71 ± 0.33</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>CDVA (logMAR)</td>
<td>0.31 ± 0.22</td>
<td>0.10 ± 0.16</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>Spherical equivalent (D)</td>
<td>-3.39 ± 3.37</td>
<td>-1.66 ± 3.03</td>
<td>.0284a</td>
</tr>
<tr>
<td>Cylinder (D)</td>
<td>-7.58 ± 2.59</td>
<td>-3.95 ± 1.99</td>
<td>&lt; .0001b</td>
</tr>
<tr>
<td>Kmax (D)</td>
<td>58.77 ± 3.97</td>
<td>54.69 ± 3.35</td>
<td>&lt; .0001a</td>
</tr>
<tr>
<td>K1 (D)</td>
<td>47.53 ± 3.38</td>
<td>46.06 ± 2.92</td>
<td>.001a</td>
</tr>
<tr>
<td>K2 (D)</td>
<td>51.98 ± 3.32</td>
<td>49.53 ± 3.16</td>
<td>&lt; .0001a</td>
</tr>
<tr>
<td>Coma (μm)</td>
<td>-4.17 ± 1.39</td>
<td>-2.73 ± 0.95</td>
<td>&lt; .0001a</td>
</tr>
<tr>
<td>CCT (μm)</td>
<td>462.2 ± 34.3</td>
<td>466.6 ± 31.8</td>
<td>.2849a</td>
</tr>
<tr>
<td>Corneal thinnest point (μm)</td>
<td>428.6 ± 36.9</td>
<td>441 ± 36.8</td>
<td>.0020a</td>
</tr>
<tr>
<td>DKmax (mm)</td>
<td>1.59 ± 1.27</td>
<td>0.87 ± 1.67</td>
<td>.0141b</td>
</tr>
<tr>
<td>DTh (mm)</td>
<td>1.82 ± 0.59</td>
<td>1.02 ± 0.34</td>
<td>.0188a</td>
</tr>
</tbody>
</table>

ICRS = intracorneal ring segments; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; D = diopters; Kmax = maximum keratometry; K1 = keratometry at flat axis; K2 = keratometry at steep axis; CCT = central corneal thickness; DKmax = distance of Kmax from corneal apex; DTh = distance of corneal thinnest point from corneal apex.

*Paired t test.

*Wilcoxon test.
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keratometric and visual outcomes after ICRS implantation.\cite{21} Peña-García et al.\cite{22} proposed that alignment of the refractive and keratometric axes (angle < 15°) is another positive prognostic factor for successful visual outcomes after ICRS implantation.

It is well documented that significant flattening of the central cornea occurs 6 months after ICRS implantation.\cite{22} The reduction in keratometry is evident in all grades of keratoconus, but the largest keratometric amelioration is observed in cases with a high degree of disease severity, as shown by Ertan and Kamburoglou.\cite{23} Moreover, Boxer Wachler et al.\cite{24} reported that patients with advanced keratoconus demonstrated the greatest decrease in spherical equivalent, which correlates well with the amount of flattening in the central cornea. The corneal flattening effect of ICRS shows an excellent long-term stability\cite{25,26} and, interestingly, it is preserved to some extent even after ICRS removal.\cite{26} However, the refractive improvement reverses after ICRS explantation, with subsequent visual deterioration.\cite{26}

The aim of our study was to investigate whether the cone eccentricity influences the visual outcomes after ICRS implantation. Central cones have higher simulated keratometry values at 3 mm and anterior corneal higher order aberrations compared to peripheral cones.\cite{27} It has also been documented that the pericentral cornea flattens more than the central cornea after ICRS implantation, thereby maintaining the prolate shape of the corneal optical zone.\cite{28,29} Shetty et al.\cite{30} showed that cone location appears to affect visual acuity after combined topography-guided photorefractive keratectomy and corneal cross-linking, with better results for cones within a central 2-mm zone. However, Greenstein et al.\cite{31} suggested that more topographic flattening occurs in central cones rather than peripheral cones after corneal cross-linking.

In our study, there was improvement of keratometric readings, UDVA, CDVA, and coma after Keraring implantation, but we did not observe any correlation between the visual outcomes and the eccentricity of the cone, as reflected by the DKmax and DTh. Both DKmax and DTh decreased significantly postoperatively. Of course, our study has certain limitations. The number of eyes included in our study was relatively small. Moreover, our study included both central (within a 2-mm zone) and peripheral (outside a 2-mm zone) cones without being able to differentiate the impact of eccentricity for these two distinct subgroups (low number of eyes).

Our data do not show any influence of the cone eccentricity on the final visual outcome after Keraring implantation for keratoconus. Larger studies are required to investigate further the effect of conus location on ICRS outcomes and validate these results.

AUTHOR CONTRIBUTIONS

Study concept and design (ZG, SH); data collection (ZG, GDP, ME, MB); analysis and interpretation of data (ZG, GDP, AK, DL, NK); writing the manuscript (ZG, GDP, NK, MB); critical revision of the manuscript (GDP, ME, AK, SH, DL, MB); statistical expertise (ZG, GDP); administrative, technical, or material support (GDP, NK); supervision (SH)

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