Effect of femtosecond-assisted intrastromal implantation of MyoRing for keratoconus on corneal asphericity
Mahmoud M. Ismail\textsuperscript{a}, Hany O. Elsedfy\textsuperscript{b}, Khaled Abdelazeem\textsuperscript{b}, Momen A.M. Aly\textsuperscript{b}

\textsuperscript{a}Department of Ophthalmology, Faculty of Medicine, Al-Azhar University, Cairo, \textsuperscript{b}Department of Ophthalmology, Faculty of Medicine, Assiut University, Assiut, Egypt

Correspondence to Khaled Abdelazeem, MD, Department of Ophthalmology, Assiut University, Assiut 71515, Egypt. Tel: +20 111 400 1717; fax: +20 882 333 327; e-mail: abdelazeem.kh@aun.edu.eg

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Purpose
The aim of this study was to evaluate the effect of implanting MyoRing into a femtosecond-created corneal pocket on corneal asphericity in patients with keratoconus.

Patients and methods
This prospective, nonrandomized, interventional clinical study included 38 eyes with keratoconus. Femtosecond-assisted implantation of MyoRing was done for all cases. The intrastromal pocket was 7.4 mm in diameter and deep at a level equal to 80% of central corneal thickness. Corneal asphericity, curvature, thickness, and elevations were evaluated 3 months after surgery.

Results
The mean age of the patients was 24.53±5.18 years at the time of surgery. The same diameter of the MyoRing was used in all cases. Both uncorrected distance visual acuity and corrected distance visual acuity significantly improved after implantation of the MyoRing. Uncorrected distance visual acuity improved from 0.05±0.01 to 0.31±0.01 and corrected distance visual acuity improved from 0.29±0.14 to 0.34±0.10. The postoperative changes in all measured refractive parameters were significantly better in comparison with the preoperative measures. The mean preoperative spherical equivalent of the refractive error was −9.87±2.91 D, whereas the postoperative spherical equivalent was −0.89±0.30 D. The refractive sphere and cylinder improved also from a preoperative value of −8.31±2.55 and −3.11±1.93 D, respectively, to a postoperative value of −0.46±0.21 and −0.86±0.32 D, respectively. The Q value of anterior corneal surface significantly improved to a less prolate shape, from −0.49±1.11 preoperatively to 0.23±0.01 postoperatively. On the contrary, the Q value of the posterior surface of the cornea showed no statistically significant change after MyoRing implantation.

Conclusion
MyoRing implantation improved the asphericity of the anterior corneal surface from advanced prolate shape to the optimal prolate Q value of −0.52 and ‘spherical aberration free’ Q value of −0.46. This improvement in corneal asphericity may have a role in increasing the postoperative visual acuity.

Keywords:
corneal asphericity, femtosecond, keratoconus, MyoRing

Introduction
Keratoconus is a bilateral progressive corneal disorder, characterized by conical deformity, thinning, and protrusion of the cornea, which induces irregular astigmatism and myopia resulting in impairment in the quality of vision [1,2]. The etiology of keratoconus is unknown and not certain. The pathogenesis is most likely multifactorial, including biochemical abnormalities, keratocyte apoptosis, and/or changes in collagen orientation and distribution [3–5].

Spectacle correction is the initial method to manage reduced visual acuity owing to keratoconus. When spectacles fail to adequately correct visual acuity or satisfy patients, contact lenses are the next option. Rigid gas permeable lenses are required in cases with severe irregularities to correct the irregular astigmatism and reduce higher-order wavefront error associated with keratoconus [6]. Contact lens-intolerant patients with clear central corneas may benefit from intracorneal ring segment (ICRS) insertion [7]. Other alternatives include the use of anterior or posterior chamber phakic intraocular lenses, including toric lenses [8]. On the contrary, corneal collagen cross-linking is an effective procedure for stabilizing the cornea in keratoconus [9–12].

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ICRS has been used, for correction of keratoconus, as an additive surgical procedure, aiming not only to delay or avoid corneal grafting in patients with keratoconus but also to improve visual acuity [13,14]. MyoRing is another type of corneal implant that has been used for management of keratoconus. It is a slightly flexible polymethyl methacrylate implant inserted into a corneal pocket. MyoRing features, such as rigidity and flexibility, allow safe, easy, and effective treatment of myopia and irregular astigmatism associated with keratoconus and keratectasia that occurs after laser in situ keratomileusis (LASIK) [15].

Corneal shape is not a perfect sphere but has a steeper curvature at its central part than its peripheral part. Therefore, corneal asphericity was considered as the main source of spherical aberration of the eye. The $Q$ value of $-0.46$ would decrease primary spherical aberration to nil [16]. The mean value of the corneal asphericity coefficient (i.e. $Q$ value) is $-0.26\pm0.18$ in human cornea (range, $-0.88$ to $+0.50$) [17]. However, the same $Q$ value, with different curvatures, will result in different amount of spherical aberration and adverse effects on visual quality. Therefore, evaluation of the $Q$ value changes in addition to the keratometric values is important [18].

The aim of this study was to evaluate the effect of implanting a complete ring (MyoRing) into a corneal pocket on corneal asphericity for visual rehabilitation in keratoconus.

**Patients and methods**

This prospective, nonrandomized, interventional clinical study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by Assiut University Institutional Review Board. A written informed consent was obtained from all study participants.

Thirty-eight eyes (29 patients) with keratoconus were enrolled in the study. Diagnosis of keratoconus was based on slit-lamp examination and Pentacam HR (WaveLight Allegro Oculyzer II, Erlangen, Germany). All included patients were in need for visual rehabilitation. The inclusion criteria were no previous ocular surgery, no corneal scar, a minimum corneal thickness of 380 μm, an average keratometry (K) reading at the central cornea of 50–65 D, myopia of at least $-5.0$ D, and contact lens intolerance. Eyes with other ocular pathology, such as glaucoma or iridocyclitis, were excluded from the study. Patients with systemic diseases, collagen vascular diseases, and autoimmune or immune-deficiency diseases were also excluded from the study.

Preoperative comprehensive examination was performed for all cases, including uncorrected distance visual acuity (UCVA), corrected distance visual acuity (CDVA) using decimal visual acuity chart, manifest refraction, cycloplegic refraction, and fundus examination. Pentacam Wavelight Oculyzer II was used to measure the corneal thickness, keratometry readings ($K_1$, $K_2$, and $K_{max}$), elevations (front and back), and $Q$ values of anterior ($Q_{ant}$) and posterior ($Q_{post}$) corneal surfaces at 6-mm diameter.

The procedure was done under topical anesthesia using Benoxinate hydrochloride 0.4% eye drops (Benox; Egyptian International Pharmaceutical Industries Co., 10th of Ramadan City, Egypt). This was followed by the use of topical moxifloxacin hydrochloride 0.5% (Vigamox; Alcon Laboratories Inc., Fort Worth, Texas, USA) eye drops as a prophylaxis against infection. Povidone iodine 5% (Betavidone; El-Nile Company for Pharmaceuticals and Chemicals Industries, Cairo, Egypt) was used for sterilization of the ocular surface. Sterilization of the eyelids and surrounding skin was done using povidone iodine 10%. Creation of the intrastromal pocket for MyoRing (Dioptex GmbH, Linz, Austria) implantation was performed by means of femtosecond technology in all cases, at Nour Al Haya Hospital in Cairo using Victus (Technolas Perfect Vision Gmbh, Bausch&Lomb, Munich, Germany) and at Al Nour Center in Assiut using WaveLight Allegretto Wave Eye-Q 400 Hz (Alcon Laboratories Inc.), to create intrastromal pocket 7.4 mm in diameter and deep at a level equal to 80% of the central corneal thickness. After creation of the pocket, a space was gently formed by spatula passing through the incision between the closed lamella and the bed.

MyoRing was inserted into this pocket through a 12 o’clock located incision; MyoRing inflates to its original circular shape once placed into the pocket. The smaller the diameter and the bigger the thickness, the higher the corrective effect that can be achieved. MyoRing diameter and thickness was adjusted according to the standard manufacturer’s nomogram [19,20], which is based on central average keratometry reading (Table 1).

Postoperative outcome measures included UCVA, CDVA, manifest refraction, keratometry readings, corneal thickness, elevations, and $Q$ values after 3
months from surgery. Postoperative data at first week and first month were not included into the analysis, as final refractive and visual results are expected to be achieved after 3 months.

Statistical analysis
Data were collected and analyzed using statistical package for the social sciences (SPSS version 20.0; IBM, Armonk, New York, USA). Continuous data were expressed in the form of mean±SD, whereas nominal data were expressed in the form of frequency and percentage. Preoperative and postoperative data of enrolled patients were compared using paired t test. P value was considered to be significant if less than 0.05 and highly significant if less than 0.001.

Results
This study included 38 eyes of 29 patients with keratoconus. The mean age of the patients at the time of surgery was 24.53±5.18 years. The same diameter of the MyoRing (6 mm) was used in all cases. Among the patients, 350-μm thickness MyoRings were implanted in 30 eyes, and 300-μm thickness MyoRings were implanted in eight eyes.

Preoperative and postoperative data of enrolled patients including visual acuity and refraction are shown in Table 2. Both UCVA and CDVA significantly improved after MyoRing implantation (Fig. 1). UCVA showed statistically significant improvement from 0.05±0.01 preoperatively to 0.31 ±0.01 postoperatively (P=0.03). CDVA improved significantly from 0.29±0.14 preoperatively to 0.34 ±0.1 postoperatively (P=0.01).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive sphere (D)</td>
<td>−8.31±2.55</td>
<td>−0.46±0.21</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Refractive cylinder (D)</td>
<td>−3.11±1.93</td>
<td>−0.86±0.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SE (D)</td>
<td>−9.87±2.91</td>
<td>−0.89±0.30</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>UCVA</td>
<td>0.05±0.01</td>
<td>0.31±0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>CDVA</td>
<td>0.29±0.14</td>
<td>0.34±0.10</td>
<td>0.01</td>
</tr>
</tbody>
</table>

CDVA, corrected distance visual acuity; SE, spherical equivalent; UCVA: uncorrected distance visual acuity. P value considered significant if less than 0.05 and highly significant if less than 0.001.

Figure 1

Changes in visual acuity before and after MyoRing implantation. CDVA, corrected distance visual acuity; UCVA, uncorrected distance visual acuity.
The postoperative changes in all measured refractive parameters were significantly better in comparison with the preoperative measures (P < 0.001). The mean preoperative spherical equivalent (SE) of the refractive error was $-9.87\pm2.91$ D, whereas the postoperative SE was $-0.89\pm0.30$ D. The refractive sphere and cylinder improved also from a preoperative value of $-8.31\pm2.55$ and $-3.11\pm1.93$ D, respectively, to a postoperative value of $-0.46\pm0.21$ and $-0.86\pm0.32$ D, respectively.

Central corneal thickness was significantly reduced postoperatively ($426.01\pm44.98$ μm) versus preoperatively ($446.23\pm33.93$ μm). The front elevation was significantly reduced after MyoRing implantation from $22.71\pm8.98$ to $8.65\pm2.01$. All other measured corneal anterior sagittal map indices ($K_1$, $K_2$, $K_{\text{max}}$ and $Q_{\text{ant}}$) also showed statistically significant improvement after MyoRing implantation. On the contrary, back elevation, and $Q_{\text{post}}$ showed no statistically significant change after MyoRing implantation. Pentacam parameters are summarized in Table 3. The changes in $Q$ values; $Q_{\text{ant}}$, and $Q_{\text{post}}$, are illustrated in Fig. 2 and Table 3.

**Discussion**

The $Q$ value is the unitless best-fit ellipsoid (conic constant) to describe apical ratio of change and is a measure of deviation of any surface from sphere; in other words, the radial change from center to peripheral of the quadric surface. It is a quantified indicator to measure the aspherical degree. As a key parameter of the mathematical model of the cornea, the $Q$ value reflects the corneal shape and optical properties such as refractive power, spherical aberration, and aberration distribution. $Q$ value of an ideal spherical surface is 0.00. A prolate surface has a negative $Q$ value, whereas an oblate surface has a positive $Q$ value [18,21,22]. Multiple studies focused on the corneal $Q$ value and its distributions, as well as its influence on optical properties of the human eye [23–26].

Intracorneal ring implantation has been used for the management of keratoconus and complies with Barraquer postulates, according to which the thickness and the diameter of the added ring determines the amount of flattening of the cornea [27]. Decrease in refractive error may not necessarily indicate visual improvement, and success of surgery should not be only evaluated by postoperative refraction. Corneal asphericity, which serves as a marker of visual quality and turning it normal, can be a predictor of visual gain. This study not only evaluated the changes in visual acuity and refraction after MyoRing implantation in patients with keratoconus but also corneal shape changes described as corneal curvature and asphericity, which may affect the quality of vision.

The significant improvement of UCVA after MyoRing implantation, from 0.05±0.01 preoperatively to 0.31±0.01 postoperatively, is owing to the significant decrease of SE, sphere and cylinder. The SE decreased from $-9.87\pm2.91$ to $-0.89\pm0.30$ D. The degree of improvement of refractive error, in the current study, was greater than other studies, which evaluated several types of corneal implants including MyoRing and ICRS [19,28–30]. On the contrary, the significant improvement of CDVA is explained by improvement of the quality of vision, which could not be achieved with the use of spectacles. The improvement of $Q_{\text{ant}}$ was statistically significant and toward a less prolate cornea, from $-0.49\pm0.11$ preoperatively to $0.23\pm0.01$ postoperatively. The change in $Q_{\text{post}}$ was not significant, from $-0.76\pm0.21$ preoperatively to $-0.47\pm0.15$ postoperatively. The changes of all anterior corneal surface parameters were statistically significant. On the contrary, the

**Table 3 Comparison between the preoperative and postoperative Pentacam parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>48.07±13.31</td>
<td>40.70±17.48</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$K_2$</td>
<td>51.31±16.87</td>
<td>43.60±12.09</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$K_{\text{max}}$</td>
<td>56.12±7.39</td>
<td>53.09±6.03</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Central corneal thickness</td>
<td>446.23</td>
<td>426.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(μm)</td>
<td>±33.93</td>
<td>±44.98</td>
<td></td>
</tr>
<tr>
<td>Front elevation</td>
<td>22.71±8.98</td>
<td>8.65±2.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Back elevation</td>
<td>51.05±13.87</td>
<td>54.60±12.98</td>
<td>0.16</td>
</tr>
<tr>
<td>$Q_{\text{ant}}$</td>
<td>-0.49±0.11</td>
<td>0.23±0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>$Q_{\text{post}}$</td>
<td>-0.76±0.21</td>
<td>-0.47±0.15</td>
<td>0.38</td>
</tr>
</tbody>
</table>

$K_1$, flat keratometry reading; $K_2$, steep keratometry reading; $K_{\text{max}}$, maximum keratometry reading; $Q_{\text{ant}}$, value of the anterior corneal surface; $Q_{\text{post}}$, value of the posterior corneal surface. P value considered significant if less than 0.05 and highly significant if less than 0.001.

![Image](image.png)

The postoperative and anterior surface anterior and posterior surface $Q$ values.

**Figure 2**
posterior corneal surface revealed no significant change after MyoRing implantation. Comparison of the preoperative anterior and posterior corneal surfaces, regarding elevations and $Q$ values, revealed more prolate posterior corneal surface and higher elevation. The preoperative $Q_{\text{post}}$ was $-0.76\pm0.21$, whereas the preoperative $Q_{\text{ant}}$ was $-0.49\pm0.11$. This proves that the posterior surface is more affected than the anterior surface in keratoconus.

### Conclusion

In conclusion, MyoRing implantation leads to a positive shift in the preoperative highly negative $Q$ value to be less negative and improvement of asphericity of the anterior corneal surface. This improvement in corneal asphericity has a role in improvement in visual acuity, in addition to the effect of decreased refractive error. More studies evaluating the corneal and total ocular wavefront changes are recommended.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

### References