DOI: https://doi.org/10.54393/pjhs.v7i6.3908

PAKISTAN JOURNAL OF HEALTH SCIENCES
(LAHORE)
https://thejas.com.pk/index.php/pjhs
ISSN (E): 2790-9352, (P): 2790-9344
Volume 7, Issue 06 (June 2026)

Original Article

OPEN ACCESS

Visual Outcome and Topographic Parameters Stability after Corneal Ring Segment Surgery in Keratoconus

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ARTICLE INFO

Keywords:
Keratoconus, Ring Segments, Femtolaser, Kmax, Topography

How to Cite:
Khan, S. Z., Khan, A. A., Rasheed, A., Saeed, R., Saeed, A., Ali, S., Malik, A. M., & Ahmed, W. (2026). Visual Outcome and Topographic Parameters Stability after Corneal Ring Segment Surgery in Keratoconus: Topographic Parameters Stability after Corneal Ring Segment Surgery in Keratoconus. Pakistan Journal of Health Sciences, 7(6), 75-80. https://doi.org/10.54393/pjhs.v7i6.3908

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Received Date: 30th January, 2026
1st Revision Received: 11th March, 2026
2nd Revision Received: 18th March, 2026
Acceptance Date: 31st March, 2026
Published Date: 30th June, 2026

ABSTRACT

Keratoconus is a bilateral, non-inflammatory disease that leads to the bulging outward of a cone-shaped cornea affecting both genders. The major symptoms are blurring of vision, distortion of images, and difficulty in night driving. **Objectives:** To find the improvement in distance best corrected visual acuity (BCVA) and maximum keratometry (Kmax) from the baseline values up to three months following the implantation of ICRS. **Methods:** This study was employed as a retrospective consecutive cohort, which included all eligible keratoconus subjects visting Out Patient Department, Fatima Memorial Hospital. All twenty-five cases underwent a comprehensive clinical ocular examination followed by Pentacam corneal topography. Those willing for the Kerrara ring segment implant for visual rehabilitation were enrolled. All surgeries were performed by a single surgeon with Femtolaser technology. **Results:** A total of twenty-five subjects were implanted with Ferrara Rings. Regarding the visual outcome, a statistically significant improvement in uncorrected visual acuity (UCVA) was observed following implantation of the Ferrara cornea rings ($p<0.001$). Similarly, the K max values also demonstrated a decreasing trend from 52.88 ± 4.80 preoperatively to 50.42 ± 4.61 postoperatively ($p<0.001$). Hence, it was documented that a reduction in Kmax values indicates a significant flattening in corneal regularity and topographic stability after Ferrara segment implantation. **Conclusions:** The results of this observational study showed a significant improvement in visual acuity and a reduction in K max values due to the spacer effects of ICRS, resulting in an overall improvement in the quality of life of Keratoconus patients.

INTRODUCTION

Keratoconus (KC) is a non-inflammatory, progressive disorder that causes the cornea to thin and bulge outward into a cone shape. This consequently distorts both the anterior and posterior surfaces of the cornea, leading to irregular astigmatism and myopia. As a result, light entering the eye is not properly focused on the retina, causing blurry, distorted vision. The condition usually develops in the late teens or early twenties and continues to progress for the next ten to twenty years before stabilizing, although the degree of progression of the disease may vary widely. These patients commonly experience various symptoms like blurring and distortion of images, increased sensitivity to light and glare, and driving at night becomes difficult due to halos around bright light. Moreover, subjects complain of frequent changes in the prescription of eyeglasses and intolerance

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to contact lenses [1]. Multiple factors have been implicated in the pathophysiology of keratoconus. In the past, it was considered primarily as a biomechanical disorder leading to bulging of the cornea. However, recent research highlighted that structural abnormalities within the cornea, disruptions in collagen lamellae, reduced levels of collagen crosslinking, and deranged lysosomal enzyme activity were the main pillars of etiology and progression of Keratoconus [2]. In addition, very recently, the significant role of immunologic changes and oxidative stress has been implicated as a causative factor. The increased levels of cytokines, including IL-1β, IL-6, IL-17, and TNF-α, along with increased apoptosis of keratocytes, have supported it [3]. Furthermore, it was postulated that high oxidative stress stimulated the collagenase and gelatinase enzymes, contributing to collagen degradation. There is a high rate of cousin marriages in this country; consequently, the role of genetic predisposition is an important risk factor leading to the development of disease in young people. Additionally, multiple environmental factors, such as high levels of humidity, wind, dust, and dirt, can lead to chronic allergic responses in the eyes. Consequently, it is associated with frequent and forceful rubbing of the eyes. All these factors have been strongly implicated, possibly by inducing mechanical stress that triggers the release of pro-inflammatory mediators, ultimately contributing to structural modifications and ectasia. Despite advancements in operative techniques for managing corneal diseases, keratoconus remains a frequent indication for penetrating keratoplasty in underdeveloped countries of Southeast Asia. Hence, there was a dire need for effective, minimally invasive interventions to manage visually debilitating conditions like keratoconus. Intrastromal Corneal Ring Segments (ICRS), Ferrara rings, are small, clear devices made up of polymethylmethacrylate (PMMA). The fundamental mechanism of ICRS involves the implantation within the mid-corneal peripheral part of the stroma. It is usually placed at approximately two-thirds of the corneal depth, outside the central optical zone. The rings act as spacer elements between corneal lamellae; these segments induce an arc-shortening effect, which effectively shortens the central arc length of the cornea and consequently flattens the central anterior conical surface of the cornea [4]. Due to this reshaping, it will regularize the irregular astigmatism and reduce the associated myopia, thereby improving visual acuity. It has been observed that the degree of corneal flattening achieved is directly proportional to the thickness and inversely proportional to the diameter of the intracorneal ring segments [5]. In addition, patient counseling, such as reduced eye rubbing and avoiding dusty, windy environments, might also contribute to perceived stability. ICRS implantation has been considered a minimally invasive and reversible procedure for keratoconus treatment [6]. Moreover, it provided a valuable option to more invasive surgical procedures like corneal transplantation, especially for cases where visual acuity could no longer be adequately corrected with glasses and subjects were intolerant to contact lenses [7].

Even though it has been shown that intrastromal corneal ring segments (ICRS) have been effective in terms of enhancing the visual acuity and corneal topography, little has been done in terms of enduring results, extensive population-based results, and even comparative outcomes with other methods of the surgery, particularly in the local population with a low socioeconomic status and with short follow-up periods. Keratoconus causes cumulative visual impairment, and most patients in developing countries have no access to effective, least invasive, and sustainable methods of treatment. As such, there is a need to assess the short-term effectiveness and safety of using ICRS implantation in enhancing the visual and topographic performance among these populations. This study aimed` to evaluate the efficacy and safety of ICRS implantation. The findings contributed preliminary data to the existing literature regarding the impact on visual, refractive, and topographic parameters and complications in patients with Keratoconus in the local population.

METHODS

This retrospective observational cohort study design was based on reviewing the electronic medical records of keratoconus patients who underwent Ferrara ring segment implantation in the cornea. The study was conducted at Fatima Memorial Hospital College of Medicine and Dentistry, Lahore. The data collection was initiated before the approval of the institutional review board. In light of this methodology, the consecutive sampling technique was employed. The study was approved by the IRB of the hospital vide reference no FMH-05/08/2025-IRB-1701 dated 15th September 2025. The smple size was calculated by using the WHO sample size formula, taking a standard deviation of nearly 3 to 4 diopters of Kmax after the implantation of Ferrara rings in the cornea. With a 95% confidence level and precision of 1.5 diopters, the minimum sample size was calculated as 21 eyes. With consideration of potential loss to follow-up, the final sample size of 25 eyes was selected [8]. After the approval, those patients who fulfilled the inclusion and exclusion criteria underwent implantation of Ferrara rings between 16 September 2025 and January 2026. The surgery was performed under topical anesthesia, with a dedicated Department of Corneal and Refractive Surgery on the Femtosecond LDV Z6 Platform at Amanant Eye

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Centre, Lahore. The inclusion criteria for each patient were a history of intolerance to glasses and contact lenses, aged more than eighteen years, best-corrected visual acuity (BCVA) less than 6/12 in both eyes, Pentacam topography confirmed the presence of keratoconus, and progression was documented on two consecutive scans at least one month apart from the previous examination. Moreover, a corneal thickness of 380 microns or greater at the 5 mm zone of the placement of stromal ring segments was established. Patients with conditions, such as a history of glaucoma and cataract surgeries, corneal cross-linking, other refractive surgeries, and keratoplasty, were also not considered for this procedure. Presence of corneal hydrops or significant central corneal scarring and active ocular infection, especially bacterial and viral keratitis or uncontrolled inflammation in either eye at the time of surgery. Moreover, known systemic collagen vascular diseases, pregnancy, autoimmune disorders, or immunodeficiency diseases were excluded from the study. In this study, visual acuity was assessed by using the Snellen charts and converted to Log MAR values for data analysis. Pentam Topograph was used for corneal topography. On line Ferrara ring calculator was used to assess the number and size of the segments [9]. To ensure reproducibility, all measurements were conducted by a single Pentacam machine and the same professionally trained optometrist. For the safety of the subjects, broad-spectrum Moxifloxacin topical drops were initiated a week before the surgery, and a sterile environment was ensured in the operating room. A close post-operative follow-up scheduled at 1st, 2nd weeks, 1 month, and 3 months was maintained.

In this study, statistical analysis was performed by using the SPSS Statistics platform with version 23.0. Continuous variables like BCVA, pachymetry readings, Kmax values were expressed as mean ± SD to check the normal distribution. Normality was assessed using the Shapiro-Wilk tests. To compare the pre- and post-operative values after Ferrara ring implantation using paired t-test was employed. In addition, the categorical variables were tabulated as frequencies and percentages. As per standardized practice, a p-value<0.050 was considered statistically significant.

RESULTS

A total of 25 patients who underwent corneal Ferrara Rings implantation for mild to moderate visually compromising keratoconus were included in this study. The mean age of patients in this series was 20.50 ± 2.75 SD years. There was a male predominance among the enrolled subjects, as 68% were male and 32% were female. During the postoperative follow-up of these cases, clinical complications were generally mild and self-limited. After the femtosecond laser docking of the footplate on the eye, subconjunctival hemorrhage occurred in 56% of patients, which resolved within a week with topical treatment. All these patients underwent a surgical procedure under short-acting topical anesthesia. During the ring insertion, due to corneal tissue handling and manipulation to implant the ring, corneal epithelial defects were observed in 11(44%) patients. However, none of these cases had developed active stromal keratitis. In addition, no segment extrusion and segment decentration were observed throughout the follow-up period. Moreover, during the early post-operative follow-up, glare or haloes were reported by 14 (56%) patients, which progressively diminished. Regarding the visual outcome, a statistically significant improvement in uncorrected visual acuity (UCVA) was observed following implantation of the Ferrara cornea rings (Table 1).

Table 1: Demographics of Study Participants

Variables	n (%)
Gender	
Male	17 (68%)
Female	8 (32%)
Complications	
Hemorrhage	14 (56%)
Corneal Lesion	11 (44%)
Keratitis	0 (0%)
Extrusion	0 (0%)
Decentration	0 (0%)
Glare/Haloes	14 (56%)

The pre-operative right-eye visual acuity assessed by the Log Mar chart showed a mean of 1.15 ± 1.43, which improved significantly postoperatively to 0.34 ± 0.16 (p<0.001). In addition, the left-eye post-operative visual assessment also demonstrated a mean of 0.35 ± 0.16, compared with a pre-operative mean of 0.85 ± 0.18. Both these improvements in the indices indicated a remarkable visual gain in both eyes following minimally invasive surgery. There was a significant flattening of corneal curvature as demonstrated on post-operative topographic measurements (Table 2).

Table 2: Comparison between Pre and Post Visual Outcomes

Visual Outcome	Mean ± SD	p-value
VA Right Eye Pre-Op	1.15 ± 1.43	<0.001
VA Right Eye Post-Op	0.34 ± 0.16	
VA Left Eye Pre-Op	0.85 ± 0.17	<0.001
VA Left Eye Post-Op	0.35 ± 0.16	

The preoperative K max for the right eye was 52.58 ± 4.12, which decreased statistically significantly to 50.42 ± 3.81 postoperatively (p<0.001). Similarly, the left-eye K max also demonstrated a decreasing trend from 52.88 ± 4.80 preoperatively to 50.42 ± 4.61 postoperatively (p < 0.001). Hence, it was inferred that a reduction in Kmax values

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would indicate an improvement in corneal regularity and topographic stability after Ferrara segment implantation (Table 3).

Table 3: Comparison Between Pre-Op and Post Op Kmax Readings

K max Cornea	Mean ± SD	Minimum	Maximum	p-value
Kmax RE Pre-Op	52.58 ± 4.12	45.00	62.40	<0.001
Kmax RE Post-op	50.42 ± 3.81	45.00	59.20	
Kmax LE Pre-Op	52.88 ± 4.80	45.00	62.40	<0.001
Kmax LE Post-Op	50.42 ± 4.61	45.20	59.20	

DISCUSSION

The present study demonstrated that Ferrara corneal ring segment implantation resulted in a marked improvement in visual acuity and a meaningful reduction in corneal steepening among patients with keratoconus. The arc shortening effect on keratoconus patients following ring implantation has also been reported in previous studies, which consequently resulted in an improvement of visual status and anterior corneal topographic parameters [10]. Colin et al. implanted the Intacs rings.They followed the post implantation Pentacam topographic scans and revealed a favourable improvement in best corrected visual acuity (BCVA) and significant reduction in Kmax in both eyes, which resulted in flattening of the cornea by approximately 1.5 to 3.75 D. The same observation was inferred in this study with BCVA improved from 1.1 ± 1.43 to 0.34 ± 0.16 (p=0.001) and Kmax 52.58 ± 4.12 to 50.42 ± 3.81(p=0.001)[11]. In the published series by Ertan *et al.* also used Femtosecond laser for the management of Keratoconus and reported a substantial improvement in vision and decreased corneal irregularity following Ferrara and Intacs segment implantation. These findings were synchronous with our findings [12]. In addition, in a case series by Sandes *et al.* evaluated the visual status after concentric ring implantation in cases of asymmetric Keratoconus. They documented better corneal regularity and a favourable visual outcome post-operatively [13]. These findings were similar to the present study as ectatic corneas had achived good regularity, hence improved vision post-operatively. Moreover, in keratoconus management, corneal topographic stability, even after placing the single segment Intacs ICRS implantation, played a significant role in predicting the post-operative visual outcome. The study by Vega-Estrada et al. analysed the clinical and Pentacam topography parameters and reported that they remained stable during the six-month to one-year follow-up [14]. In the present study, all cases were followed both clinically and with Pentam topography and had a good, stable visual and refractive outcome. However, due to social and economic constraints, most of the patients were followed 3 months postoperatively. During post-operative follow-up, no vision-threatening complications like infectious keratitis, segment migration, or extrusion were observed. However, Bautista-Llamas reviewed post-operative data of Keratoconus cases and reported a minimum rate of complications, which led to migration and explantation of intrastromal corneal ring segments [15]. Moreover, two large series analysed the post-operative complications and documented that 6.1% ICRS were explanted from a total cohort of 572 eyes. They divided it into two groups; out of these, 2.6% were explanted for medical complications, and 3.5% for unfavourable refractive outcomes [16, 17]. Contrary to this, no device was explanted in this study. This difference might be due to the strict sterilization measures practiced in the operating room and meticulous refractive and topographic assessment by modern Pentacam topography. In addition, we performed all the procedures by using a Femtosecond laser with a predefined precise depth of the corneal tunnel [18]. In contrast, due to meticulous pre and post-operative monitoring, not a single case of migration or extrusion, or infectious keratitis of the device was reported in this study. Izquierdo *et al.* formalised a series of 40 eyes of central Keratoconus operated with Femtolaser z6 with good visual status. It was substantiated that both visual acuity and mean keratometry readings had statistically significant improvement (p<0.001) after 1 year follow-up [19]. In the present study, the same methodology was practiced, and good visual and keratometry outcomes were inferred by using Femtolaser in ectatic corneas. In another retrospective study, Monterosso *et al.* opted for deep lamellar keratoplasty in Keratoconus patients. They authored a BCVA of 0.9 ± 0.08 Log MAR and zero rate of graft failure post-operatively. On the contrary, the safety and efficacy of the Ferrara corneal ring documented in this study strengthen the evidence supporting ICRS as a viable option in the management of keratoconus, particularly in countries where a cornea bank system does not exist and donor corneal tissue availability is very limited [20].

There were a few limitations in this study. Due to the socioeconomic constraints, most of the keratoconus patients resort to non-surgical options like glasses and contact lenses. However, due to the progressive nature of the disease, it usually progresses to an advanced form of ectatic cornea. This resulted in a small sample size for intra-stroma rings, which were indicated for mild to moderate cases of keratoconus. Moreover, our patients belonged to far-flung areas of the province, and due to difficulty in boarding and lodging in a cosmopolitan city, we had short follow-ups with the patients. In future studies, a larger sample size, longer follow-up, and a comparison between Femtolaser-coupled deep lamellar keratoplasty and femtosecond-assisted ring implantation are

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recommended to validate the stability and adaptability of ICRS by the ophthalmologist.

CONCLUSIONS

Ferrara corneal ring segment implantation demonstrated significant improvement in visual outcome and reduced corneal topographic evidence of steepening in patients with keratoconus. This procedure has proven its effectiveness as a minimally invasive method for visual rehabilitation in keratoconus patients.

Authors' Contribution

Conceptualization: SZK
Methodology: SZK, RS
Formal analysis: AAK, AR, SA, WA
Writing and Drafting: SZK, AAK, AS, AMM
Review and Editing: SZK, AAK, AR, RS, AS, SA, AMM, WA

All authors approved the final manuscript and take responsibility for the integrity of the work

Conflicts of Interest

All the authors declare no conflict of interest.

Source of Funding

The authors received no financial support for the research, authorship and/or publication of this article.

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