Clinical Outcomes of Intrastromal Corneal Ring Segments Implantation with a New Nomogram Based on Cone Location and Q-Value in Keratoconus Patients

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Abstract

Background: Keratoconus (KC), a progressive corneal disorder, poses significant challenges to visual acuity and quality of life. Intrastromal Corneal Ring Segments (ICRS) implantation holds promise as a treatment option for KC.

Objectives: This study aimed to assess the effectiveness of personalized Intrastromal Corneal Ring Segment (ICRS) implantation based on cone location and Q-value, utilizing a newly developed nomogram, in improving visual and refractive outcomes for keratoconus patients.

Patients and methods: Fifty eyes of 50 keratoconus patients were enrolled in a prospective, randomized controlled clinical study. The study employed a newly developed nomogram to determine the choice of single or double ICRS implantation based on cone location and the Q-value of the cornea. Visual acuity, refractive status, keratometry, corneal thickness, topographic parameters, and corneal asphericity were assessed preoperatively and postoperatively over 12 months. Statistical analysis was performed to evaluate the significance of the results.

Results: Using our new nomogram revealed significant improvements in various visual and refractive parameters after 3 months. Uncorrected Distant Visual Acuity (UDVA) and Corrected Distant Visual Acuity (CDVA) showed substantial enhancement, along with reductions in Refractive Sphere and Refractive Cylinder, all of which were statistically significant ($P < 0.0001$). These improvements were maintained over the subsequent 9 months, indicating the efficacy and durability of our new nomogram.

Conclusion: Our study introduces an innovative and personalized approach to the management of keratoconus through the development and application of a new nomogram. By considering the individual characteristics of each patient's cornea, including cone location and Q-value, we were able to tailor the implantation method for optimal corneal reshaping and restoration. Our results demonstrated significant improvements in visual acuity, refractive measures, and corneal curvature, highlighting the effectiveness of our new nomogram.

Keywords: Keraring; Nomograms; Keratoconus; Q-value; Intrastromal corneal ring segments.

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Introduction

Keratoconus (KC) is a bilateral and progressive non-inflammatory corneal disorder characterized by the presence of corneal irregularities. It frequently results in a decline in both visual acuity and visual quality due to the emergence of progressive myopia and astigmatism. The estimated prevalence of this condition is approximately 1.38 cases per 1,000 individuals. **(Hashemi et al. 2020)**

During its initial phases, Keratoconus (KC) can be effectively addressed through conservative approaches such as prescription spectacles or rigid contact lenses. In more advanced stages, surgical interventions like deep lamellar keratoplasty and penetrating keratoplasty (PK) may be contemplated. Nevertheless, the potential for complications and technical complexities has underscored the necessity for exploring alternative treatments. **(Keane et al. 2014; Gomes et al. 2015; Arnalich-Montiel et al. 2016)**

Implanting Intrastromal Corneal Ring Segments (ICRS) serves to flatten the central corneal curvature, thereby reducing refractive errors and keratometry values, while also enhancing Uncorrected Distant Visual Acuity (UDVA). This offers promise in diminishing the necessity for keratoplasty **(Ertan and Colin 2007; Liu et al. 2015)**

The advent of femtosecond laser-assisted surgery has significantly increased the popularity of ICRS implantation among cornea surgeons. This surge in popularity can be attributed to the safety, simplicity, and precision of the procedure. The utilization of an exceptionally precise cutting device, made possible by femtosecond laser technology, supplants the traditional manual approach for intrastromal ring implantation **(Said et al. 2016; Monteiro et al. 2020)**

Various types of ICRS, such as Keraring segments (Mediphacos Inc., Belo Horizonte, Brazil), Ferrara ring segments (AJL Ophthalmic S.A., Vitoria-Gasteiz, Spain), and INTACS ring segments (Addition Technology, Inc., Lombard, IL, USA), are extensively employed to rectify refractive abnormalities in individuals with keratoconus. These devices work to regularize the anterior corneal surface, reducing both myopic and astigmatic components**. (Vega-Estrada and Alio 2016)**

Most of nomograms used in ICRS procedures are based on empirical data and lack a precise mathematical model to describe the impact of ICRS on the ectatic cornea. These nomograms currently fall short of providing accurate predictability, leading to frequent instances of unexpected refractive and visual outcomes after surgery. Presently, extensive efforts are being invested in enhancing these nomograms to capture the biomechanical responses of the ectatic cornea more accurately to ICRS implantation, with the aim of improving the ability to predict the final refractive and visual results. **(Sakellaris et al. 2019)**

Nevertheless, it is essential to acknowledge that nomograms may not be universally accurate across all types of corneal cones, as the complexities and variations of these conditions are vast and cannot be fully addressed by a theoretical nomogram alone. In practice, most nomograms rely on empirical data rather than being based on a precise mathematical model of the ring segments' impact on the ectatic cornea.**(Piñero and Alio 2010)**

Numerous studies have been conducted to evaluate the efficacy of single or double ICRS implantation, with the choice depending on the location of the corneal cone. For example, Utine et al. in 2021 **(Utine et al. 2021)** conducted research to determine the optimal approach based on the cone's location. Likewise, Iqbal et al. in 2021 **(Iqbal et al. 2021)** explored the suitability of single or double-ring segment implantation based on the cornea's Q-value. These investigations contribute to the expanding body of research focused on identifying the most suitable ICRS implantation strategy, considering factors such as cone location and corneal characteristics.

Our study aims to assess whether single or double-ring segments implantation is more appropriate, utilizing a newly developed nomogram (NN) as a guideline. The choice of implantation method will be determined based on the precise cone location and the Q-value of the cornea.

Patients and methods

The research protocol for this prospective, randomized controlled clinical study received ethical approval from the Institutional Review Board of the Qena Faculty of Medicine, South Valley University, Egypt, and the ethical approval number is SVU-MED-OPH026-4-23-9-728. Surgeries were conducted in collaboration with private eye centers.

Our study enrolled a total of 50 keratoconic eyes belonging to 50 patients. Prior to their inclusion, all participants received a thorough briefing regarding the condition, its clinical presentations, the available treatment choices, and the potential risks associated with the surgical procedure. Only after this comprehensive discussion was completed, each patient was presented with an informed consent form and proceeded with the surgical intervention upon providing their consent.

The inclusion criteria for this study comprised patients with keratoconus who met the following conditions: a clear central cornea without any corneal scarring or other complications; inability to tolerate rigid contact lenses; a documented record of undergoing corneal cross-linking (CXL) at least six months prior to enrollment; a minimum corneal thickness of 350 microns at the thinnest point and 450 microns at the insertion point; and a mean keratometry (K mean) value below 59 D.

The study employed distinct exclusion criteria to ensure the selection of suitable participants. These criteria encompassed the presence of corneal scarring, a documented history of keratorefractive surgery, atopic conditions, allergies, autoimmune disorders, prior herpetic infections, and a history of other ocular ailments unrelated to keratoconus. These exclusion criteria were established to minimize potential confounding variables and maintain the study's emphasis on patients with keratoconus who did not possess these specific conditions or medical backgrounds.

Each patient underwent a thorough eye examination, which encompassed preoperative assessments of visual acuity. Both Uncorrected Distant Visual Acuity (UDVA) and Corrected Distant Visual Acuity (CDVA) were evaluated using the logarithm of the minimum angle of resolution (logMAR) scale. Refractive status was assessed by examining the refractive sphere, cylinder, and spherical equivalent (SE). A meticulous examination of the anterior segment was conducted using a slit lamp to scrutinize its structures. Fundus examinations were performed to evaluate the posterior segment of the eye. Additionally, various topographic and tomographic parameters were analyzed, including keratometry measurements such as K max, K mean, K1, and K2, as well as anterior and posterior elevation. Corneal thickness, topographic cylinder, and Q-values of both the anterior (Q-anterior) and posterior (Q-posterior) corneal surfaces were assessed. Furthermore, the Belin ABCD grading system was employed for measurement purposes.

Surgical procedures

In our study, corneal topography assessments were conducted using the

Oculus Pentacam device (Oculus Optikgeraete GmbH; Wetzlar, Germany). For the tunneling procedures, we employed the iFS advanced femtosecond laser system (Abbott Laboratories Inc., Abbott Park, IL, USA). The Keraring intrastromal corneal ring segments used in the implantation are constructed from polymethyl methacrylate (PMMA) material. These segments have an optical zone with a 5 mm diameter and a triangular cross-section.**(Gupta et al. 2023)**

The corneal tunneling process was carried out with the following iFS parameters: The corneal tunnel depth was set at 80% of the corneal thickness (CTT). The inner diameter of the tunnel was 5 mm, while the outer diameter was 5.9 mm. The entry cut had a length of 1.40 mm and a thickness of 1 mm. The orientation of the incision was determined based on the steepest meridian. An energy level of 1.95 μJ was utilized for both the ring energy and the entry cut energy.**(Nacaroglu et al. 2023)** Prior to the surgery, patients were administered topical anesthetic eye drops containing 0.4% benoxinate hydrochloride. This was done 15 minutes before the procedure. Subsequently, patients were instructed to maintain their focus on a flashing light, which aided in locating the center of the cornea. To stabilize the eye and assist in the tunneling process, a suction ring was gently placed on the eye. The integrity of the tunnel was verified by inserting a spatula. **(Fig.1) (Iqbal et al. 2021)**

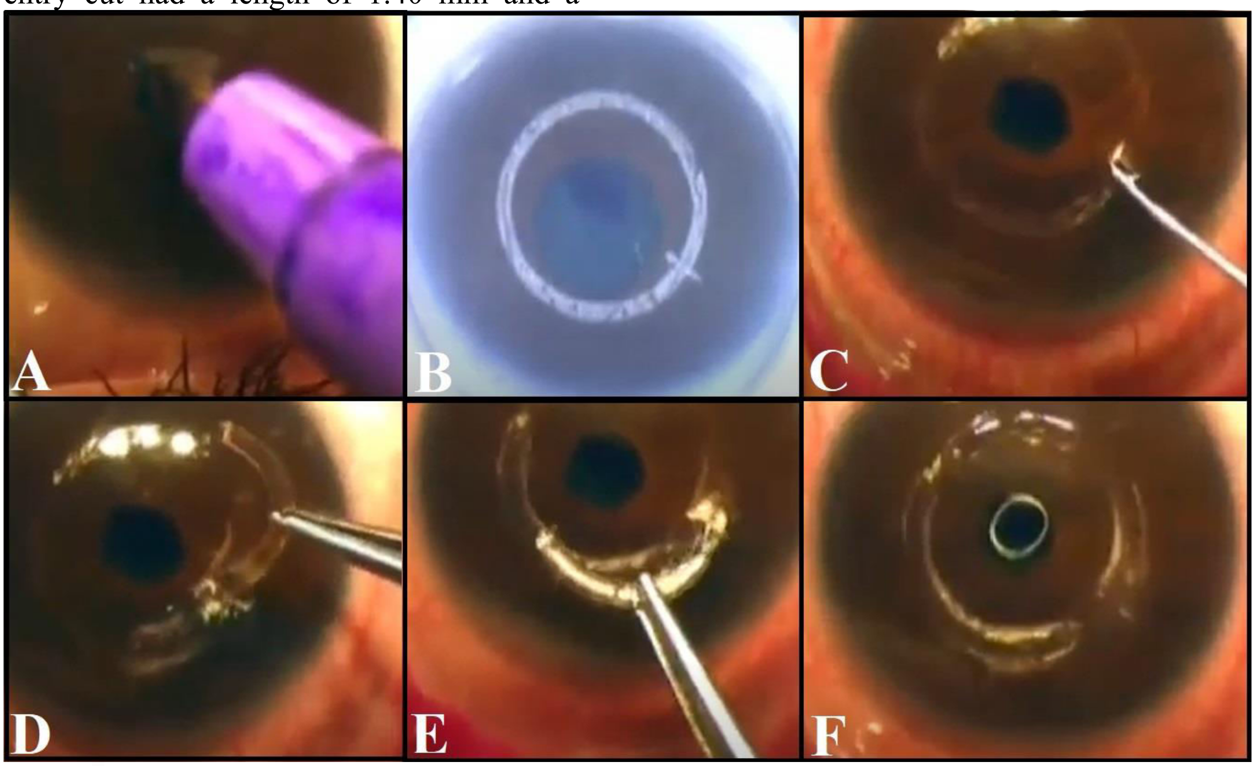

Fig. 1. Surgical Technique. (A) Marking the corneal center. (B) Corneal tunneling using iFS advanced femtosecond laser system. (C) The integrity of the tunnel was verified by inserting a spatula. (D and E) Intrastromal corneal ring segments are introduced (F) Corneal ring segments after implantation.

Implantation of Keraring single or double ring segments was carried out in accordance with the newly developed nomogram (NN) **(Table.1)**. The choice between single or double ring segments depended on factors such as the location of the corneal cone and the Q-value of the cornea.

Table 1. New nomogram (NN) for Keraring implantation depending on cone location and Q-value

Asymmetric Cone Location	Q-anterior	CTO < 450 µm Degree/µm	CTO 450- 500 µm Degree/µm	CTO > 500 µm Degree/µm
	>-0.50	160/150	160/200	160/250
	-0.50 to >-1	160/200	160/250	160/300
	-1 to -1.50	160/200 90/150	160/200 90/200	160/250 90/200
	<-1.50	160/200 90/200	160/250 90/200	160/300 90/200
Central Cone Location	**Q-anterior**	**CTO < 450 µm Degree/µm**	**CTO 450- 500 µm Degree/µm**	**CTO > 500 µm Degree/µm**
	>-0.50	160/150 160/150	160/200 160/150	160/250 160/200
	-0.50 to >-1	160/200 160/200	160/250 160/250	160/300 160/300
	-1 to -1.50	160/200 160/150	160/200 160/200	160/250 160/200
	<-1.50	160/200 160/200	160/250 160/200	160/300 160/200

CTO= corneal thickness at optical zone.

The location of the cone was determined according to keratometric values and the steep axis. A reference line was drawn along the steep meridian on the sagittal topography map. Corneal asymmetry type was determined by studying the steep area on each side of the reference meridian. If the reference line separates the steep area into two equal parts, the cone's location is described as "Central." If the line divides the steep area into unequal parts, the cone's location is said to be "Asymmetric."**(Utine et al. 2021)**

Postoperative follow-up

All patients adhered to the same postoperative topical therapy regimen. This involved the application of antibiotic eye drops containing 0.5% moxifloxacin hydrochloride, steroidal eye drops containing 1% prednisolone acetate, and lubricating eye drops. During the initial week following surgery, all eye drops were administered five times daily, with a gradual reduction in frequency in the subsequent weeks. This standardized postoperative treatment strategy was implemented to prevent infection, mitigate inflammation, and ensure adequate lubrication to facilitate the healing process after the procedure.**(Iqbal et al. 2021)**

After the surgery, patients underwent a comprehensive ocular examination on days 1, 7, and 14, and then again after one month. Corneal topography readings were obtained quarterly for a duration of one year as part of the follow-up protocol.

Statistical analysis

The collected data were subjected to analysis using STATA version 17.0 (Stata Statistical Software: Release 17.0, College Station, TX: StataCorp LP). The Shapiro-Wilk normality test was employed to assess the distribution of variables. Descriptive statistics such as means, medians, ranges, and standard deviations were used to represent quantitative data. To compare means between two sets of normally distributed data, the Student t-test was utilized. In cases where the data did not follow a normal distribution, the Mann-Whitney U test was employed to determine statistical significance. For comparisons between postoperative and preoperative results, either a paired t-test or Wilcoxon matched-paired signed rank test was applied, depending on the distribution of the postoperative data. Charts and graphs were created using Microsoft Excel 2021. Statistical significance was considered at or below the 0.05 level.

Results

This study revealed a substantial improvement in visual acuity parameters following intrastromal corneal ring segment (ICRS) implantation in keratoconus patients. Uncorrected Distant Visual Acuity (UDVA) and Corrected Distant Visual Acuity (CDVA) showed a significant enhancement after 3 months, with mean values for UDVA decreasing from 1.09 to 0.48 and for CDVA from 0.59 to 0.25 ($P < 0.0001$ for both) **(Fig.2)**. Moreover, Refractive Sphere and Refractive Cylinder exhibited remarkable reductions, with mean values decreasing from -6.61 to -2.39 and from -6.26 to -3.39, respectively, also indicating significant improvements after 3 months ($P < 0.0001$ for both). These improvements remained relatively stable throughout the subsequent 9 months, emphasizing the efficacy and durability of ICRS in treating keratoconus patients **(Fig.3)**. Nonetheless, it is noteworthy that the 12-month comparison to the 3-month outcomes revealed some variations, with Refractive Sphere and Refractive Spherical Equivalent (SE) demonstrating significant differences ($P = 0.01$ and $P = 0.007$, respectively), suggesting that further long-term evaluation is warranted. **(Table.2)**

Table 2. Visual Acuity and Refractive Changes Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months

N=50	UDVA	CDVA	Ref. sphere	Ref. cylinder	Ref. SE
Before Mean ± SD Median (range)	1.09±0.20 1.10 (0.70:1.52)	0.59±0.10 0.60 (0.40:0.82)	-6.61±1.78 -6.75 (-9.25:-3.0)	-6.26±2.15 -6.25 (-10:-2.27)	-9.68±2.30 -9.25 (-13.25:-5.25)
After 3 months Mean ± SD Median (range)	0.48±0.09 0.52 (0.40:0.70)	0.25±0.08 0.22 (0.15:0.40)	-2.07±2.43 -1.75 (-6.5:2.75)	-3.21±2.37 -2.75 (-9.0:-0.75)	-3.59±2.78 -3 (-9:1.25)
After 6 months Mean ± SD Median (range)	0.48±0.09 0.52 (0.40:0.70)	0.25±0.08 0.22 (0.15:0.40)	-2.55±2.48 -2.25 (-7:2.0)	-3.76±2.30 -3.0 (-9.25:-1.25)	-4.49±2.82 -3.75 (-10.25:0.5)

After 9 months Mean ± SD Median (range)	0.48±0.09 0.52 (0.40:0.70)	0.25±0.08 0.22 (0.15:0.40)	-2.38±2.72 -1.25 (-7.75:1.5)	-3.6±2.45 -3 (-9.75:-0.75)	-4.24±3.25 -2.5 (-10.25:1.0)
After 12 months Mean ± SD Median (range)	0.48±0.09 0.52 (0.40:0.70)	0.25±0.08 0.22 (0.15:0.40)	-2.39±2.53 -1.5 (-6.75:0.75)	-3.39±2.81 -2.75 (-10.75:0.25)	-4.12±3.29 -3.25 (-10.25:1.0)
P compared after 3 months and before	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
P compared after 12 months and 3 months	1.00	1.00	0.01	0.42	0.007

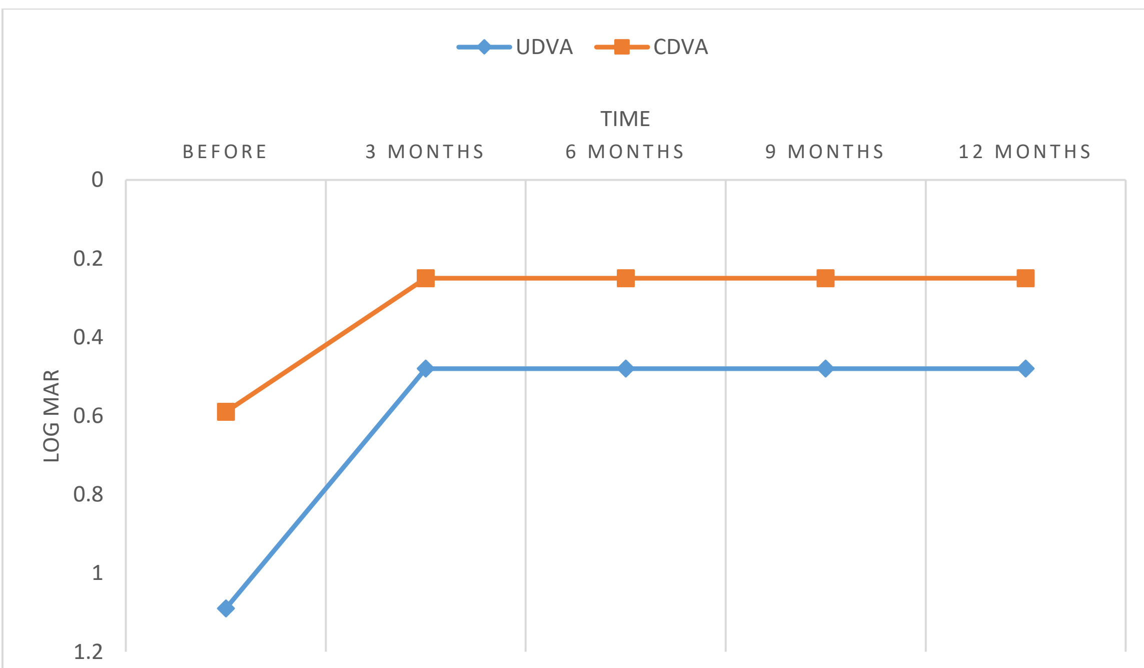

Fig.2. Visual Acuity Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months

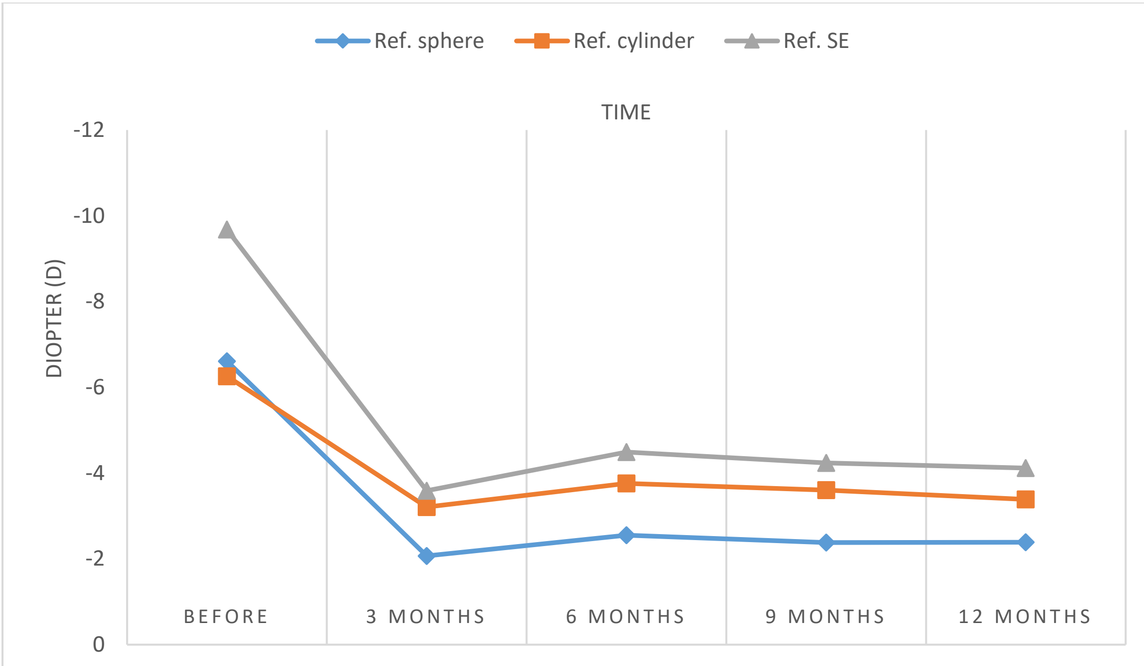

Fig.3. Refractive Changes Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months

Pachymetry measurements showed an increase in corneal thickness after 3 months, with a mean value of 426 µm, indicating a potential stabilization of the corneal thickness following ICRS implantation. Notably, this change was not statistically significant (P = 0.06), suggesting that corneal thickness remained relatively consistent over this period. K max, K main, K1, and K2, which represent keratometry values, displayed significant reductions after 3 months (P < 0.0001 for all). K max decreased from a mean of 67.75 to 64.49, while K main decreased from 54.53 to 50.07, K1 decreased from 52.09 to 48.55, and K2 decreased from 57.3 to 51.76. These reductions reflect a flattening of the central corneal curvature, which aligns with the intended effect of ICRS implantation. **(Fig.4)** However, when comparing the 12-month results to those at 3 months, K main and K1 showed a statistical significance (P = 0.10 and P = 0.01, respectively), indicating potential variability in these parameters. **(Table. 3, Figs. 5,6)**

Table 3. Corneal Changes in Pachymetry and Keratometry Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months.

N=50	Pachymetry	K max	K main	K1	K2
Before Mean ± SD Median (range)	419.44±30.02 407 (386:494)	67.75±6.60 69.2 (59:78.3)	54.53±3.69 53.9 (49.2:61.9)	52.09±3.66 51.3 (47.6:58.7)	57.3±4.18 56.6 (50.9:65.5)
After 3 months Mean ± SD Median (range)	426±31.91 414 (384:499)	64.49±6.84 63.8 (55.3:77)	50.07±3.60 48.7 (45.8:56.3)	48.55±3.60 47.6 (43.6:55)	51.76±4.01 51 (47:57.8)

After 6 months Mean ± SD Median (range)	426.92±31.50 416 (385:502)	64.41±6.81 63.2 (54.6:76.6)	50.30±3.65 49.1 (45.7:56.3)	48.52±3.60 47.4 (43.5:55.1)	52.02±4.10 51.1 (46.5:57.8)
After 9 months Mean ± SD Median (range)	427.12±30.73 416 (387:501)	64.17±6.53 62.9 (55.5:76.1)	50.29±3.57 49.4 (45.7:55.7)	48.54±3.60 47.7 (42.8:54.6)	51.98±4.01 50.6 (46:58.4)
After 12 months Mean ± SD Median (range)	428.28±29.94 420 (381:503)	64.18±6.88 64.6 (54.5:76.1)	50.1±3.46 49.7 (46.1:56.1)	48.07±3.61 47.6 (42.2:54.8)	52.08±3.99 51 (47:58.8)
P compared after 3 months and before	0.06	<0.0001	<0.0001	<0.0001	<0.0001
P compared after 12 months and 3 months	0.03	0.10	0.85	0.01	0.08

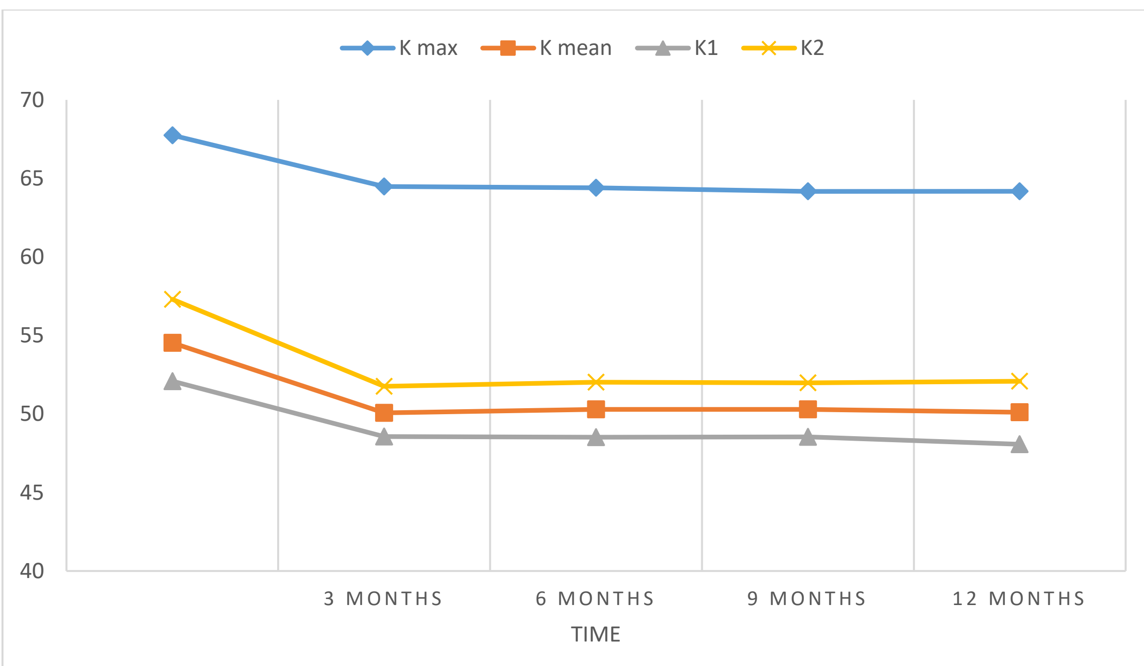

Fig. 4. Keratometry Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months

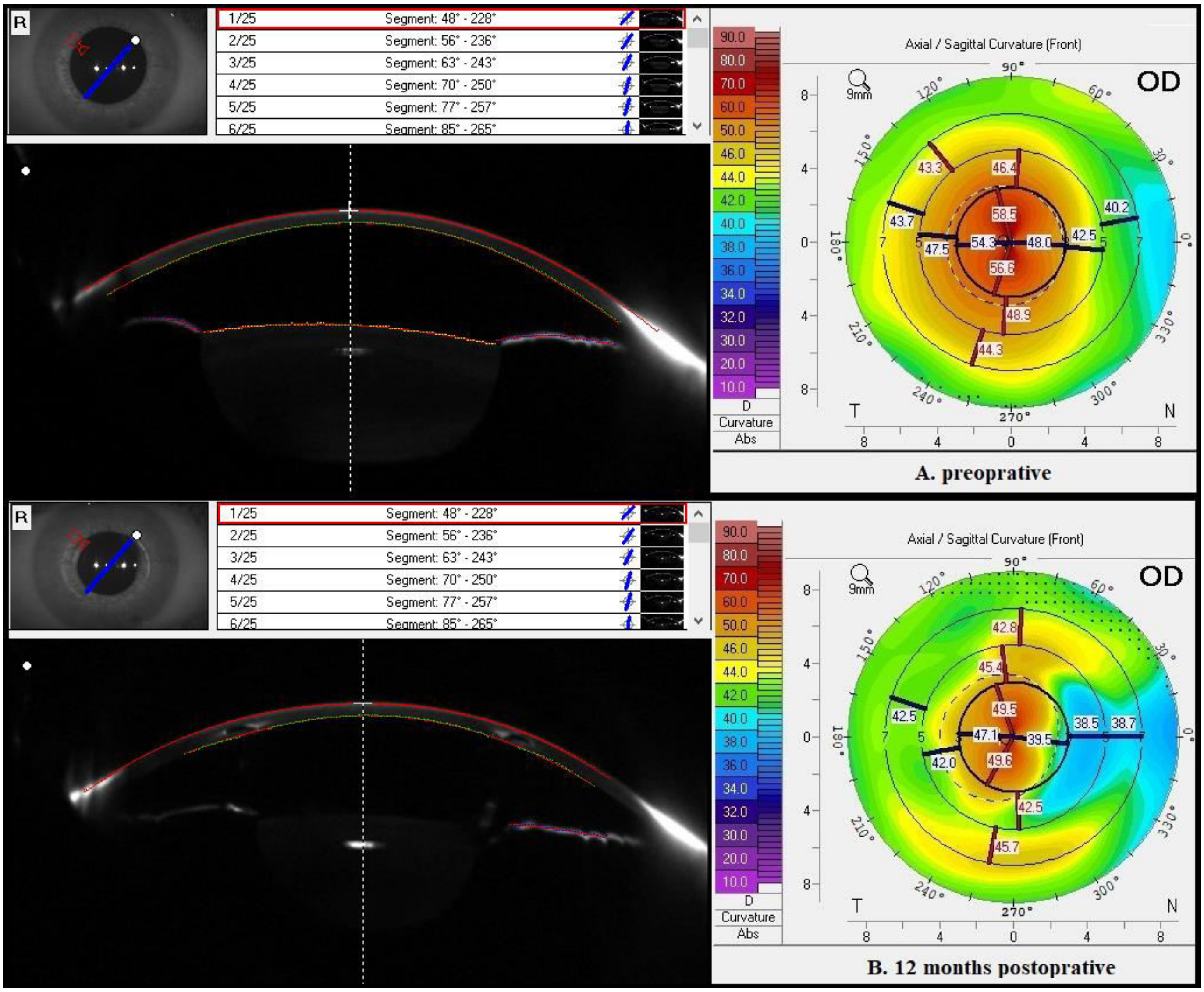

Fig.5. Example of central cones changing A. preoperative and B. 12 months postoperative.

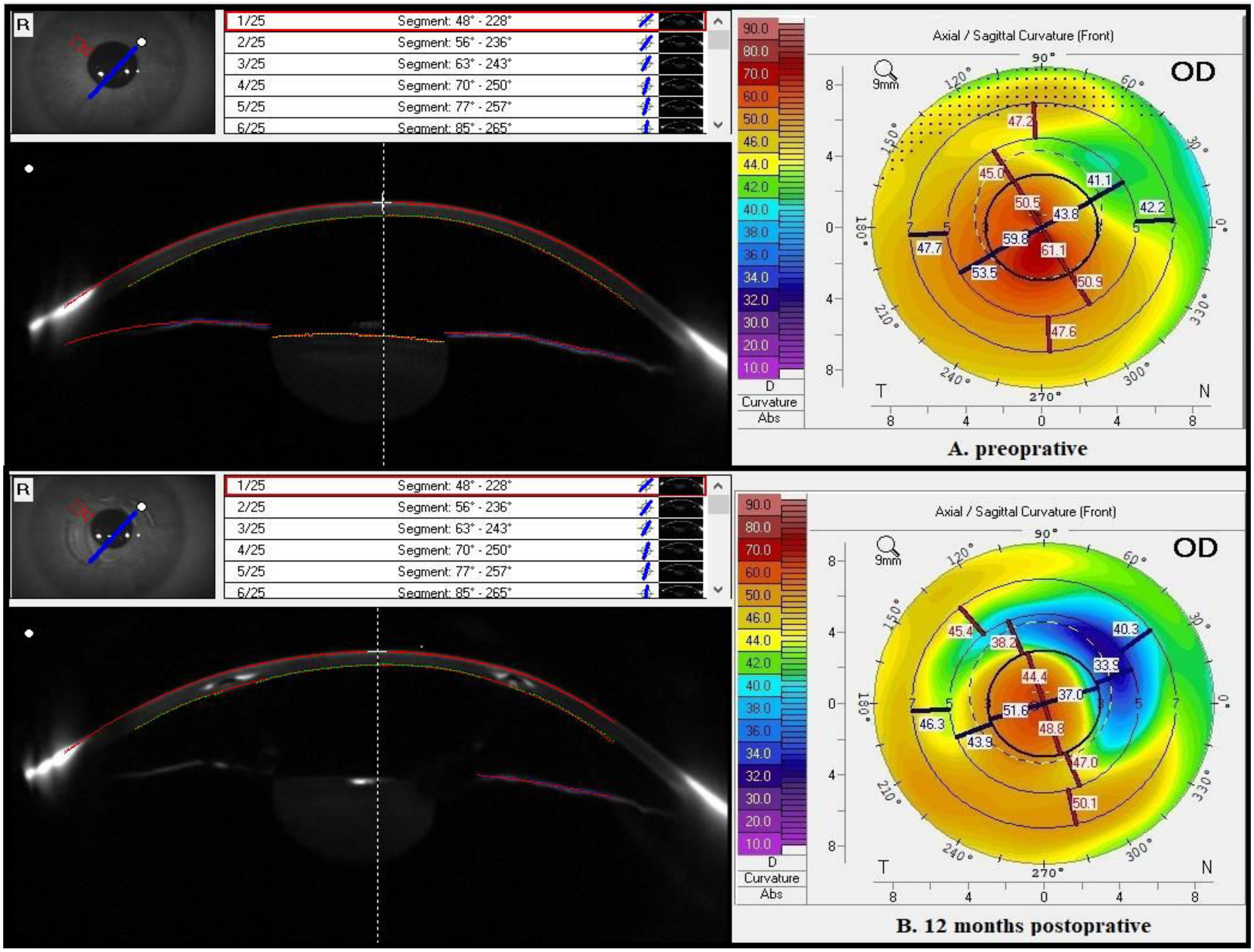

Fig.6. Example of Asymmetrical cones changing A. preoperative and B. 12 months postoperative

Notably, anterior elevation exhibited a marked decrease from a mean of 44.84 µm before the procedure to 33.56 µm after 12 months, indicating a consistent flattening of the anterior corneal surface. Posterior elevation, while decreasing, did not show a statistically significant change when comparing baseline and 12-month measurements, but a significant shift was observed between 3 months and 12 months (P = 0.008). The Q-value for the anterior corneal surface demonstrated a substantial shift from -1.47 to -0.70 (P < 0.0001), though the difference between the 3-month and 12-month results was not significant (P = 0.27). The Q-value for the posterior corneal surface remained relatively stable. Additionally, a significant reduction in astigmatism (Cylinder) was observed, decreasing from 5.22 to 4.01 (P < 0.0001). These findings collectively indicate that ICRS implantation results in the flattening of the corneal surface and a reduction in astigmatism, with most changes stabilizing over the 12-month period, providing valuable insights into the corneal topographic alterations associated with ICRS treatment for keratoconus patients. **(Table. 4)**

Table 4. Corneal Elevation, Q-Value, and Cylinder Changes Before and After Intrastromal Corneal Ring Segment (ICRS) Implantation in Keratoconus Patients Over 12 Months

N=50	Ant. Elevation	Post. elevation	Q-value Ant.	Q-value post	Cylinder
Before Mean ± SD Median (range)	44.84±17.79 41 (23:109)	86±30.27 85 (45:176)	-1.47±0.46 -1.45 (-2.2:-0.57)	-1.65±0.50 -1.79 (-2.42:-0.46)	5.22±2.59 5.4 (1.1:11.1)
After 3 months Mean ± SD Median (range)	35.72±19.37 29 (21:118)	91.68±31.19 85 (53:155)	-0.65±0.63 -0.68 (-1.83:0.07)	-1.79±0.70 -1.96 (-2.84:-0.5)	3.21±2.37 2.8 (0.8:9.2)
After 6 months Mean ± SD Median (range)	34.72±20.53 31 (16:123)	92.84±32.37 78 (56:155)	-0.63±0.66 -0.73 (-1.83:0.83)	-1.79±0.69 -1.87 (-2.84:-0.15)	3.5±2.58 2.9 (0.6:10.2)
After 9 months Mean ± SD Median (range)	34.08±19.76 32 (16:118)	91.28±31.49 81 (47:151)	-0.64±0.63 -0.65 (-1.93:0.73)	-1.79±0.69 -1.97 (-2.89:-0.05)	3.44±2.67 2.9 (0.2:10.8)
After 12 months Mean ± SD Median (range)	33.56±20.06 30 (16:115)	93.36±32.42 81 (41:158)	-0.70±0.72 -0.75 (-2.13:0.93)	-1.79±0.68 -1.97 (-2.71:-0.15)	4.01±3.22 2.9 (0.6:13.5)
P compared after 3 months and before	<0.0001	0.06	<0.0001	0.008	<0.0001
P compared after 12 months and 3 months	0.008	0.39	0.27	0.87	0.0003

Discussion

In our study, the approach we adopted was unique and innovative, particularly in the context of keratoconus management. We focused not only on flattening the cornea but also on meticulously restoring the cone to its original position, a crucial aspect often overlooked in conventional treatments. Our emphasis on considering both the cone location and the Q-value of the cornea allowed for a more personalized and targeted intervention. The foundation of our study lay in the development and application of our newly generated nomogram (NN), which was meticulously designed to address the specific needs of individual keratoconic patients.

One of the key features of our NN was its focus on restoring normal corneal asphericity. By setting a target Q-value derived from rigorous measurements, we aimed to achieve optimal corneal refraction, ultimately maximizing visual acuity. This approach departed from the conventional methods that often neglected the importance of corneal asphericity in achieving favorable outcomes. Our commitment to understanding the intricacies of the cornea, particularly its asphericity, allowed us to offer patients a more predictable and, most importantly, a more favorable visual experience following treatment.

A noteworthy aspect of our study was our consideration of the cone tissues as a cohesive unit. Traditional approaches, including the manufacturer-supplied standard nomogram (SN), might inadvertently lead to a general flattening of the cornea, potentially causing the cone tissues to redistribute randomly. This redistribution, if not carefully managed, could compromise the overall effectiveness of the treatment. Our NN, however, approached the repositioning of cone tissues with precision. By addressing them as a single unit and aiming to restore their pre-ectatic positions, we enhanced the potential for achieving the best visual and refractive results. This tailored and customized approach ensured that each patient's unique corneal characteristics were considered, leading to more consistent and optimized outcomes.

Furthermore, our study challenged the existing paradigms by underlining the importance of maintaining the cone tissues' initial position. This critical consideration was pivotal in our approach, ensuring that the corneal reshaping process was not only effective but also sustainable over time. By prioritizing the restoration of the cornea to its pre-ectatic state, we aimed not only for immediate postoperative success but also for long-term stability and visual quality for our patients.

The studies conducted by Utine et al., 2021 **(Utine et al. 2021)** and Iqbal et al., 2021 **(Iqbal et al. 2021)** shed valuable insights on the nuances of intrastromal corneal ring segment (ICRS) implantation in the context of keratoconus management. These findings offer significant contributions to the growing body of research aimed at refining and personalizing the treatment strategies for this challenging corneal disorder.

In the study by Utine et al., 2021 **(Utine et al. 2021)** a key observation was that double ICRS implantation led to more substantial improvements in various keratometry measurements, topographic astigmatism, and the asphericity of the anterior corneal surface when compared to single ICRS implantation. This suggests that the choice between single or double ICRS implantation may be influenced by the characteristics of the individual's keratoconic cone.

Notably, the study found that patients with entirely asymmetric cones achieved comparable visual, refractive, and tomographic outcomes following single ICRS implantation, which were on par with the results obtained from double ICRS implantation in cases of central and slightly asymmetric cones. This insight highlights the importance of tailoring the treatment approach to the specific cone morphology, ensuring that the choice of implantation method aligns with the patient's unique condition. Furthermore, the hypothesis that single ICRS implantation may lead to central cone displacement provides a novel perspective on the potential mechanisms underlying the differential outcomes associated with various ICRS implantation strategies.

In the study conducted by Iqbal et al., **(Iqbal et al. 2021)** the effectiveness of a

Q-value-based nomogram for single Keraring segment implantation was compared to the standard manufacturer-supplied nomogram. The results revealed that the Q-value-based nomogram approach resulted in notably improved visual acuity, refractive sphere, and various corneal curvature values, such as K2, K mean, and K Max. Additionally, the Q-value of the anterior corneal surface showed significant improvement when compared to the standard nomogram group. This emphasizes the significance of considering the Q-value as a guiding parameter in ICRS implantation, particularly when aiming for better visual outcomes and corneal remodeling.

However, it is worth noting that the standard nomogram group demonstrated better improvements in refractive cylindrical correction. This finding suggests that while the Q-value-based nomogram may excel in certain aspects of treatment, the choice of nomogram should be tailored to the specific needs of the patient, considering the nature and degree of astigmatism correction required.

The research conducted by Fariselli et al., 2021 **(Fariselli et al. 2020)**, an artificial neural network (ANN) was employed to guide the implantation of ICRS as a treatment for keratoconus. The study involved 20 eyes that received ICRS based on the ANN's guidance and compared them to another 20 eyes in which ICRS implantation was determined using the manufacturer's nomograms (SN). The findings demonstrated that the group guided by the ANN exhibited superior corrected visual acuity and a reduction in coma-like aberrations in comparison to the group following the standard nomograms. This novel ANN-driven approach holds significant potential for enhancing outcomes in keratoconus patients, with the prospect of further improvements as the ANN continues to accumulate knowledge from additional cases.

Many patients in our region frequently encounter difficulties when it comes to using contact lenses (CL), primarily due to the demands of their occupations, such as those in construction or farming, as well as the hot climate prevalent in our area. These factors contribute to the discomfort and inconvenience associated with wearing CL. Moreover, not all patients can consistently maintain proper eye hygiene and adhere to the daily care routines required for CL. Given these challenges, Keraring implantation emerges as an especially attractive alternative for individuals who find contact lenses impractical. Despite the potentially higher cost associated with ICRS implantation, it presents a more feasible and enduring solution to meet their vision-related needs.

Our study demonstrated significant improvements in visual acuity, refractive measures, corneal curvature, and corneal asphericity following Keraring implantation. Our new nomogram exhibited greater improvements in visual outcomes, refractive sphere, cylinder, spherical equivalent, keratometric measurements (all $p < 0.05$).

The improved outcomes in our new nomogram group can be attributed to the personalized approach of our nomogram, which considered the specific cone location and Q-value of the cornea. By tailoring the implantation method based on these factors, our new nomogram achieved better corneal reshaping and restoration of corneal asphericity. Restoring the cone to its original position and aiming for a more normal corneal asphericity contributed to superior visual and refractive outcomes in this group.

The outcomes of our study are consistent with other research that highlighted the importance of individualized approaches and the incorporation of Q-value in keratoconus treatment. The study by

Utine et al., 2021 **(Utine et al. 2021)**, emphasized the benefits of double ICRS implantation for certain cone locations, while Iqbal et al., 2021 **(Iqbal et al. 2021)**, found that a Q-value-based nomogram led to improved outcomes compared to the manufacturer's standard nomogram. These studies, along with our research, underscore the significance of considering individual factors and optimizing corneal reshaping for better results in keratoconus management.

Our new nomogram's focus on preserving the original position of cone tissues allowed for more cohesive and targeted corneal reshaping, resulting in better corneal stability and flattening. This finding aligns with the goals of keratoconus treatment, which aims to restore corneal shape and stability for improved visual acuity and visual quality.

It's essential to acknowledge the limitations of our study. Initially, our sample size was relatively small, and our follow-up period spanned only 12 months. Future research endeavors with more extensive participant pools and extended observation periods could yield more robust and compelling data. Furthermore, the applicability of our findings may be constrained by the specific nomograms and ICRS models employed in our study. Consequently, further investigations are needed to evaluate the effectiveness of various nomograms and types of ICRS in attaining the best possible outcomes for individuals with keratoconus.

Conclusion

Our study introduces an innovative and personalized approach to the management of keratoconus through the development and application of a new nomogram. By considering the individual characteristics of each patient's cornea, including cone location and Q-value, we were able to tailor the implantation method for optimal corneal reshaping and restoration. Our results demonstrated significant improvements in visual acuity, refractive measures, and corneal curvature, highlighting the effectiveness of our new nomogram. We emphasize the importance of considering these individual factors in keratoconus treatment, aiming not only for immediate postoperative success but also for long-term corneal stability and visual quality. Further research and refinement of nomograms are necessary to optimize outcomes in keratoconus patients undergoing ICRS implantation.

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