International Journal of Life Sciences, Biotechnology and Pharma Research Vol. 13, No. 8, August 2024 Online ISSN: 2250-3137
Print ISSN: 2977-0122

DOI: 10.69605/ijlbpr_13.8.2024.2

ORIGINAL RESEARCH

Efficacy of corneal collagen crosslinking procedure (C3-R) as a therapeutic modality in keratoconus patients

[1]Dr. Malhar Vyas, [2]Dr. Kanav Bhanot, [3]Dr. Swati Tomar

[1]Assistant Professor, [2]Junior Resident, [3]Professor, Department of Ophthalmology, NIMS&R, Jaipur, India

Corresponding author
Dr. Malhar Vyas
Assistant Professor, Department of Ophthalmology, NIMS&R, Jaipur, India
Email- malharvyas87@gmail.com

Received Date: 23 June, 2024 Accepted Date: 27 July, 2024

ABSTRACT
Keratoconus (KC) is a common bilateral, non-inflammatory, degenerative axial ectatic condition of the cornea in which the cornea assumes an irregular conical shape. The aim of thisstudy was to assess how effective corneal collagen cross-linking (CXL) is as a treatment for KC. A total of 63 participants were included, comprising 43 males (68.25%) and 20 females (31.74%). After the procedure, participants were followed up at 3-day, 10-day, 4-month, and 6months from date of surgery. At the 4-month follow-up, there was a significant improvement in Best Corrected Visual Acuity (BCVA), with the mean for the right eye decreasing to 0.48 0.39 and for the left eye to 0.43 0,39. The results from the study's comprehensive analysis andresults strongly affirm the effectiveness of CXL as an effective therapeutic approach for managing KC in children. The observed potential modifications in corneal biomechanics and shape dynamics that occur post-procedure are crucial for assessing the long-term effects of the procedure on corneal health and refractive outcomes in KC patients. The evidence gathered not only showcases the notable improvements in visual acuity resulting from the procedure but also provides valuable insights into how the cornea responds and adapts to the treatment.
Keywords: Keratoconus, corneal collagen crosslinking, corneal biomechanics.

INTRODUCTION
Keratoconus (KC) is a common bilateral, non-inflammatory, degenerative axial ectatic condition of the cornea in which the cornea assumes an irregular conical shape [1]. These changes may result in visual impairment due to irregular astigmatism, progressive myopia, or corneal scarring. The disease most often occurs at puberty [2-5]and progresses until the age of about 30 to 40 years before stabilizing. Keratoconus is a rare cause of amblyopia and visual impairment in children, as the development of visual function generally continues until the age of 8 to 11 years. Studies have reported prevalence figures varying between 0.08% and 12% according to the study and country of origin [6-11]. Young age appears to be associated with more severe forms of keratoconus and faster disease progression, with an inverse correlation between age and severity [5,6]. In addition, young age at diagnosis is linked to a greater risk of developing corneal opacity and requiring a corneal transplant [8,9].

Pediatric keratoconus seems to progress faster and to be more advanced at the time of diagnosis than keratoconus in adults [6-8]. Due to its advanced stage at diagnosis, paediatric keratoconusbears a higher risk of severe visual impairment due to irregular astigmatism, progressive myopia, or corneal scarring, thus resulting in a greater need for penetrating keratoplasty [9-11].In India, the ectasia progresses at a more rapid rate in paediatric patients with vernal keratoconjunctivitis (VKC) [12]. Because of the patients young age, keratoconus often has a significant negative effect on their quality of life [13-15]. Keratoconus is one of the most common causes of corneal transplantation in children, after congenital corneal opacities, with figures in about 15% to 20% of all corneal transplants in children [16,17]. Treatment of paediatric cases of keratoconus in comparison to the adult form demonstrates several distinctive issues, such as poor patient compliance, higher rates of intolerance to contact lens wear, and higher rates of corneal graft rejection [18-21].

Corneal biomechanics [18-20] changes vastly with age from newborn all the way through to old age. The viscoelastic nature of the young cornea enables it to rebound to its original shape far more easily during

DOI: 10.69605/ijlbpr_13.8.2024.2

early childhood. There is a period when the elasticity of the cornea reduces, and the stiffness and rigidity of the cornea increases through what is believed to be a natural cross- linking process. This process will continue but slows down during adulthood. The transition between these two phases of the cornea may open a gap during which the corneacan be affected by KC more easily, before the cornea has stiffened but still has significant elasticity. The true cause and mechanism of KC is unknown, but the corneal hysteresis (CH) (ability to absorb energy) and corneal resistance factor (CRF) (ability to resist external forces) are both reduced. CH is the difference in pressure between the first and second applanation points and the CRF is related to the elastic properties of the cornea and calculated using a linearequation.

Eyes with KC have a significantly lower CH, and CRF compared with normal eyes. This may be the consequence of distortion of the lamellar matrix in the stroma that no longer follows an orthogonal pattern, with regions of highly aligned collagen intermixed with regions there is little aligned collagen. KC may influence the development of natural stiffness within the corneaallowing the change in elasticity to assume a behavior like that of plastic, whereby the originalshape is not regained following external forces or even forces which are usually resisted by a normal cornea. This would allow us to understand why diabetics are less likely to develop severe KC.

Collagen Cross Linking [22-29]

Riboflavin-ultraviolet A (UVA) – induced collagen cross-linking of the cornea (CXL) is a novel approach that aims at increasing the mechanical and biochemical stability of the stromal tissue, and to slow down or arrest KC progression to delay or avoid recourse to keratoplasty by creating additional chemical bonds inside the corneal stroma by means of photopolymerization in the anterior two thirds of the stroma. Before the seminal paper by Spoerl & Seiler suggesting that ecstatic disease such as KC may benefit from CXL. CXL was developed for lens material following phacoemulsification and epikeratoplasty. Currently riboflavin was found to be a suitable photosensitizer as it was nontoxic, water-soluble and penetrated the corneal stroma easily without epithelium on the cornea. CXL stiffens the cornea by 328 % increasing Young's modulus by 4.5, and so increasing rigidity preventing development of an increasingly misshapen cornea. In a cornea where the elasticity is not supportive enough to return it to a normal shape in the presence of pressure, CXL would allow rigidity to prevent the stretching of tissue.

With no adequate prospective randomized control trials (RCT) in adult CXL, there is even less evidence for CXL in children. Initially, CXL was advised to be limited to those aged 18 or over,but it is clear that the ectatic process begins earlier than this age1. Sorters et al. suggested the use of CXL in children who showed progression. Arora et al. established by their review of 15patients that CXL was safe and had good visual and topographic outcomes at 12 months. Similarly, Chatzis et al. with a longer follow-up time and increased patient number (average 3years and 59 eyes, respectively), were more conclusively able to ascertain that while CXL was effective in halting progression, this effect was lost in 55 % patients by 36 months (increase in Kmax by > 1 D). More importantly, during the study period, Chatzis was able to confirm that 88 % of patients progressed, suggesting that with such a high progression rate in these patientswho have early KC, treatment should not be withheld until progression has been documented.

Kankariya et al. also specifically reviewed paediatric KC management, and this review has suggested that the current evidence would only advise what has already been the protocol for adult patients.

1. Current paediatric cross-linking guidelines [30-32]

Epithelium-off corneal cross-linking (Epi-Off) CXL is the current gold standard. The treatment should be restricted to corneas thicker than 400 μm for isotonic riboflavin and for those less than 400 μm, current recommendation to use hypotonic riboflavin solution. Epi-On CXL can be used in those patients with thinner corneas (<400 μm) and would be a preferable method especially in children due to better tolerance and better safety. Other options include the use of accelerated CXL to increase the power (9mW/cm2) but shorten the duration (10 min) with equivalent effectiveness to standard protocol and no adverse effect on the endothelium.

AIM & OBJECTIVES

AIM

- To study the efficacy of Corneal Collagen Cross linking procedure in patients with keratoconus.

OBJECTIVES

- To identify the cases of keratoconus.
- Performing corneal collagen cross linking (C3-R) in patients with keratoconus and checking the progression of keratoconus
- Compiling the data and checking the efficacy of corneal collagen cross linking (C3-R) in stopping the progression of keratoconus in patients with keratoconus.

RESEARCH HYPOTHESIS

- What is the efficacy of Corneal collagen crosslinking procedure (C3-R) as a therapeutic modality in keratoconus patients?

OUTCOME MEASUREMENT

Primary Outcome

- Best corrected visual acuity (BCVA) outcomes at 4 & 6 months
- Mean refractive spherical equivalent (MRSE) outcomes at 4 & 6 months.

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Secondary outcome

- Changes in Sim K astigmatism values pre-& post operatively
- Changes in Keratometry Max (Kmax) pre-& post operatively
- Changes in Central corneal thickness pre-& post operatively

METHODOLOGY

Study Design

- Interventional Hospital Based Study

Study Duration

- Patients were recruited from 1 July 2022 – 31 December 2023 (18 months)

Study Area

- The study will be conducted in Department of Ophthalmology, National Institute of Medical Science and Research, Jaipur.

Study Population

- Keratoconus patients of either sex coming to ophthalmology OPD/IPD of NIMSHOSPITAL, JAIPUR

Sample Population

- All patients from the study population who qualify the inclusion/exclusion criteria and were willing to participate in the study.

Justification of Sample Size- Formula for sample size calculation

$$(Z\alpha/2 + Z1\text{-}\beta)^2 \times p \times (1\text{-}p) / d^2$$

$$(1.96 + 0.84)^2 \times 0.04\ (1\text{-}0.04) / (0.05)^2$$

$$=120.42$$

(~ 120 SAMPLES)

- Z α/2 INVERSE NORMAL PROBABILITY AT 95% CONFIDENCE INTERVAL
- Z 1-β INVERSE NORMAL PROBABILITY AT 80% POWER OF THE TEST
- p= prevalence rate of keratoconus
- d= margin of error (5% considered)

Inclusion Criteria

- Keratoconus patients with progressive loss of vision and not improving with spectacles or contact lenses were included in the study.
- Thickness of cornea at its thinnest point should be more than 350 microns
- No central corneal scarring
- Max corneal curvature should be less than 63D

Exclusion Criteria

- Patients with pachymetry less than 350 microns
- Patients with hydrops
- One eyed patient
- Full thickness corneal Scars
- Patients/patients guardians not willing for follow-up
- Patients/patients guardians not giving consent to be enrolled in the study
- The study protocol and informed consent were approved by the from Institutional Scientific and Ethics Committee of National Institute of Medical Sciences, Jaipur (Rajasthan). The study was done in accordance with the Declaration of Helsinki.

All patients fulfilling the study criteria were enrolled into the study after consenting for the same, the selected patients underwent the following evaluations.

1. Demographic data and Baseline data like medical record number, age, gender
2. Detailed medical history (including ocular and family history)
3. Uncorrected (UCVA) and Best corrected visual acuity (BCVA) testing by Snellen's charts was done & converted in LogMAR values.
4. Retinoscopy examination with subjective and dynamic refraction including spherical & cylindrical powers, MRSE, and scissoring of red reflex
5. Slit lamp examination of anterior segment
6. Dilated fundus examination with stereoscopic biomicroscope aided by +90D lens
7. Corneal Topography using NIDEK PENTACAM. To detect keratoconus by assessment of KISA INDEX 9

Diagnosis and Grouping

Diagnosis of the disease was made by careful slit lamp examination and PENTACAM topography by analysing 2 visit parameters & were followed up at 4th & 6th months. The eyes were classified based on the criteria published by Rabinowitz. Severity at diagnosis was assessed using Krumeich's staging. The patients who showed progression of the disease underwent surgical intervention based on their 2nd

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visit clinical & topographical analysis.

Informed Consent

An informed consent was taken from the patient/guardian after explaining the procedure and outcome of the surgery in detail, including the possibility of various complications in their local language. Patient/ guardian was explained the need for frequent follow-ups during the study period.

Data collection technique and tools

All the patient data was collected from primary source by an individualistic interview, observation, and complete ophthalmic examination of the subjects in the study. The data collected was later entered into a Microsoft Excel sheet for a complete database.

Intervention

All surgical procedures were performed by a single surgeon having experience in cross linking. The procedures were performed under general or regional anaesthesia after gaining informed consent.

CROSS LINKING PROCEDURE

In our setup, CXL is done according to the accelerated collagen cross linking procedure, with epithelium off technique with isotonic riboflavin for corneas thicker than 400 μm and hypotonic riboflavin for those less than 400 μm.

The central 9-mm corneal epithelium is removed with a Tooke's knife after instillation of topical ethyl alcohol 10%. An 8 mm rim of trephinated CXL sponge is placed on the cornea. The cornea is then soaked with 0.1 % Riboflavin 5 phosphate with 20 % dextran in isotonic cases & 0.1 % Riboflavin 5 phosphate with 10 % dextran in hypotonic cases for every 2 minutes for 20 minutes, followed by continuous instillation of the solution every 5 minutes and administration of ultraviolet A light 365 nanometre (UV-X illumination system) for 10 minutes, with an irradiance of 9 mW/cm2 and total energy of 5.4 J/cm2. After the procedure is done, the riboflavin solution is washed off and a sterile Bandage contact lens is placed on the eye.

POSTOPERATIVE MANAGEMENT AND FOLLOW UP

Post operatively all patients were kept on.

- Topical moxifloxacin (0.5%) plus Dexamethasone (0.1%w/v) eye drops 3 times a day for 3days till BCL is removed
- Topical preservative free lubricant carboxy methyl cellulose 0.5 % eye drops 6 times a day for 1 month.
- Topical Hydroxy propyl methyl cellulose 0.3% w/w Ointment 4 times a day for 1 month

Bandage Contact lens is removed after 3 days or after complete reepithelialisation, whicheveris first.

Follow up

After surgery patients were followed up at 3-day, 10-day, 4-month, 6 months from date of surgery.

On 4 & 6 month of follow-up, following tests were performed.

- Vision (UCVA & BCVA) using Snellen chart & converted in LogMAR values.
- Refraction to calculate MRSE
- Corneal topography using NIDEK PENTACAM to calculate K1, K2, K-average, TCT
- Anterior Segment Optical Coherence Tomography using NIDEK RS 3000

RESULTS

In this study, a total of 63 participants were included, comprising 43 males (68.25%) and 20 females (31.74%). The mean age of the participants was 17.57 years, with a standard deviationof 3.40 years.

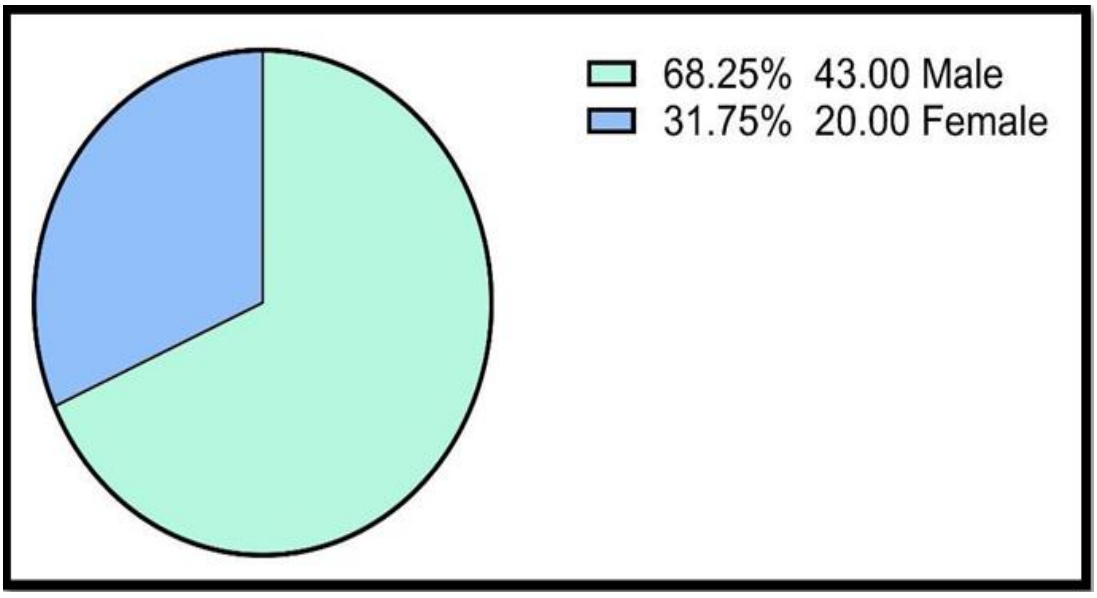

Figure 1. Gender description among the enrolled participant.

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This gender distribution reflects a predominantly male representation within the sample, constituting over two-thirds of the total participants. The age range and standard deviation indicate a relatively narrow and consistent age distribution among the participants, providing a focused demographic profile for the study's analyses and interpretations **(Table 1).**

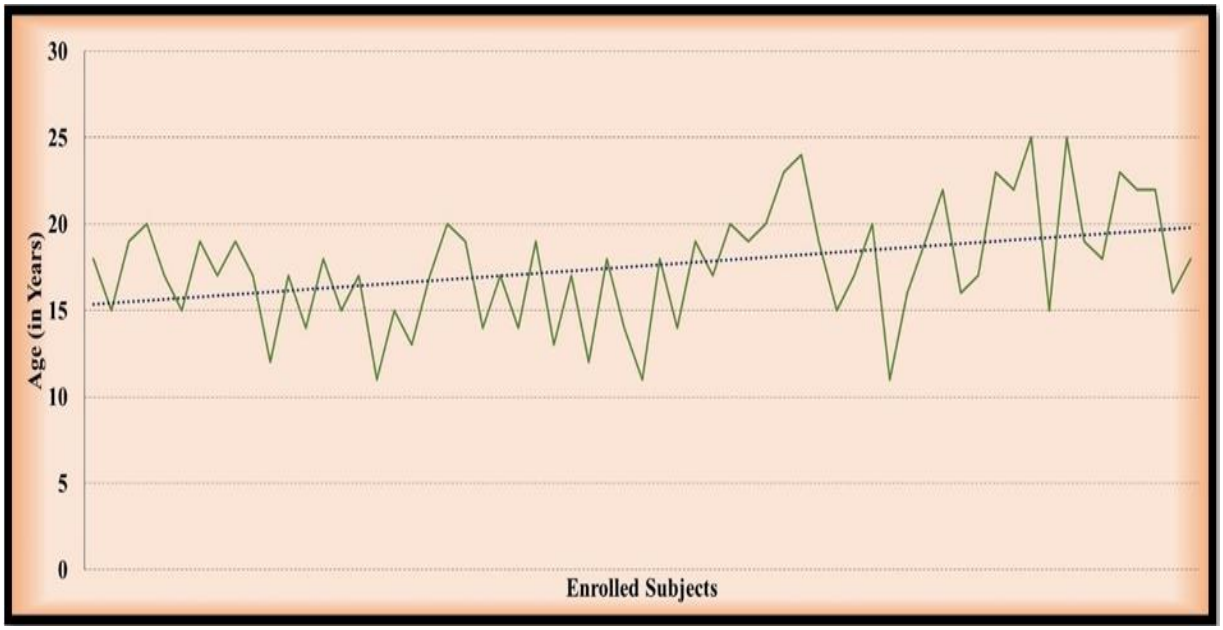

Figure 2. Age of the subjects enrolled in the study

Table 1: Demographic Details of the enrolled subjects.

Variables	**N (%)**
Total Sample Size	63 (100)
Male, n (%) Female, n (%)	43 (68.25) 20 (31.74)
Age **(mean ± SD)**	17.57 ± 3.40
All the data is presented in n, number and percentage (%)	

Best Corrected Visual Acuity (BCVA)

The Best Corrected Visual Acuity (BCVA) data for both right and left eyes are presented across different time points. Before the procedure, the mean BCVA for the right eye was 0.56 ± 0.44, and for the left eye, it was 0.47 ± 0.56. Following the procedure, at the 4-month follow-up, there was an improvement in BCVA, with the mean for the right eye decreasing to 0.48 ± 0.39 and for the left eye to 0.43 ± 0.39.

Table 2. BCVA of the enrolled patients upon different periods of follow-up.

BCVA				
Follow-up Period	**Right**	**p-value***	**Left**	**p-value***
Pre-Operative (mean ± SD)	0.56 ± 0.44	**<0.01**	0.47 ± 0.56	**<0.01**
Post-Operative 4 Month (mean ± SD)	0.48 ± 0.39		0.43 ± 0.39	
Post-Operative 6 Month (mean ± SD)	0.29 ± 0.34		0.26 ± 0.33	

This improvement continued at the 6-month post-operative assessment, with the mean BCVA for the right eye further decreasing to 0.29 ± 0.34 and for the left eye to 0.26 ± 0.33. These findings suggest a positive impact of the corneal collagen cross-linking procedure on visual acuity in keratoconus patients over time, highlighting its efficacy as a therapeutic interventionin managing this condition.

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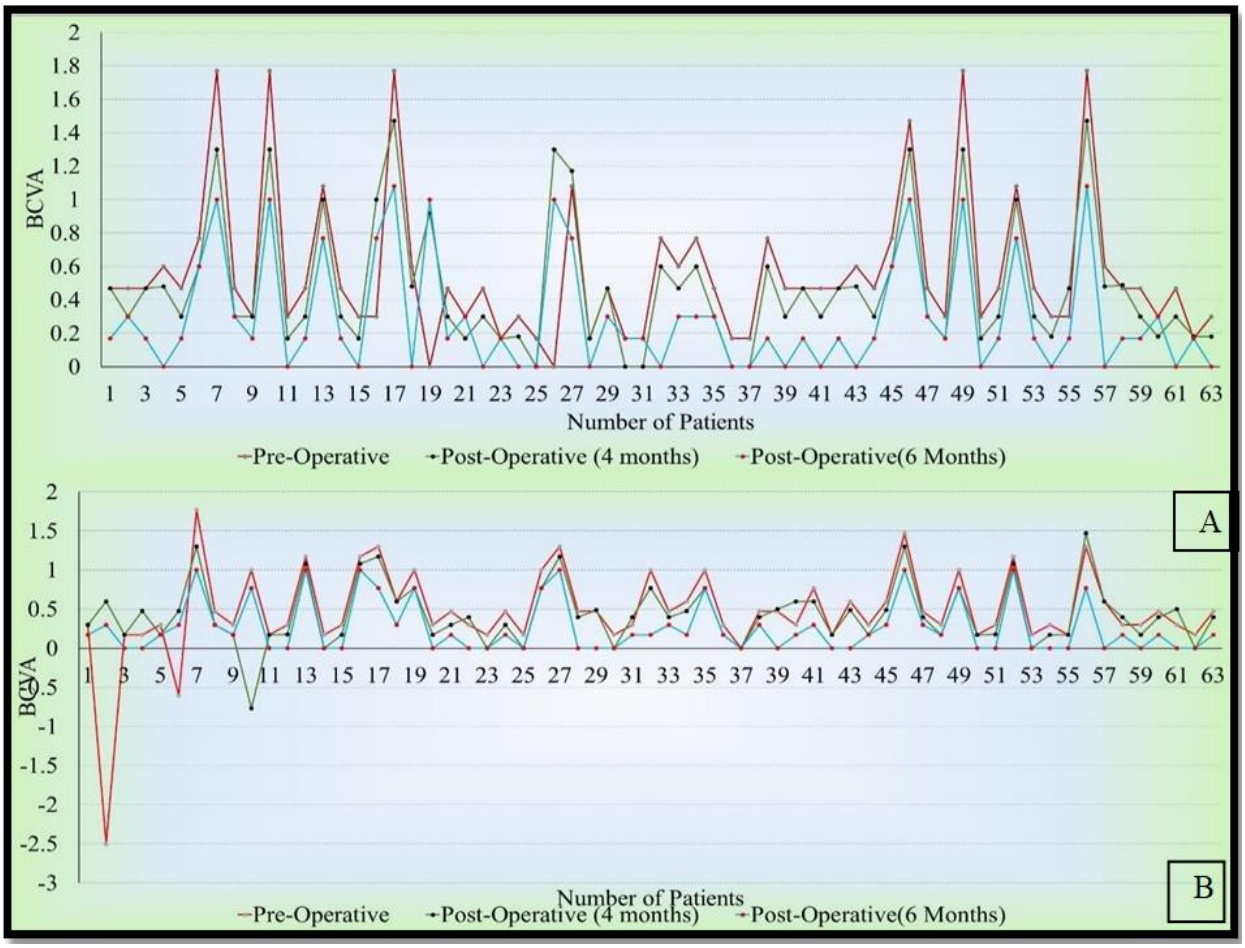

Figure 3. Line chart showing BCVA of A. Right B. Left eye of the subjects enrolled in thestudy among different follow-up periods.

Keratometry (K1)

Keratometry (K1) data for both right and left eyes are presented across different time points. Before the procedure, the mean K1 for the right eye was 46.94 ± 4.64 diopters, and for the left eye, it was 47.53 ± 4.36 diopters. Following the procedure, at the 4-month follow-up,there was an increase in K1, with the mean for the right eye increasing to 47.84 ± 4.64 diopters and for the left eye to 48.43 ± 4.36 diopters.

Table 3. K1 of the enrolled patients upon different periods of follow-up.

K1 (D)				
Follow-up Period	**Right**	**p-value***	**Left**	**p-value***
Pre-Operative (mean ±SD)	46.94 ± 4.64	**<0.01**	47.53 ± 4.36	**<0.01**
Post-Operative 4 Month (mean ± SD)	47.84 ± 4.64		48.43 ± 4.36	
Post-Operative 6 Month (mean ± SD)	46.71 ± 4.50		46.08 ± 4.39	
The data is presented in mean ± SD.				

This trend reversed at the 6-month post-operative assessment, with the mean K1 for the right eye decreasing slightly to 46.71 ± 4.50 diopters and for the left eye to 46.08 ± 4.39 diopters. These findings suggest dynamic changes in corneal curvature following corneal collagen cross-linking, indicating potential alterations in corneal shape and refractive characteristics over time after the procedure.

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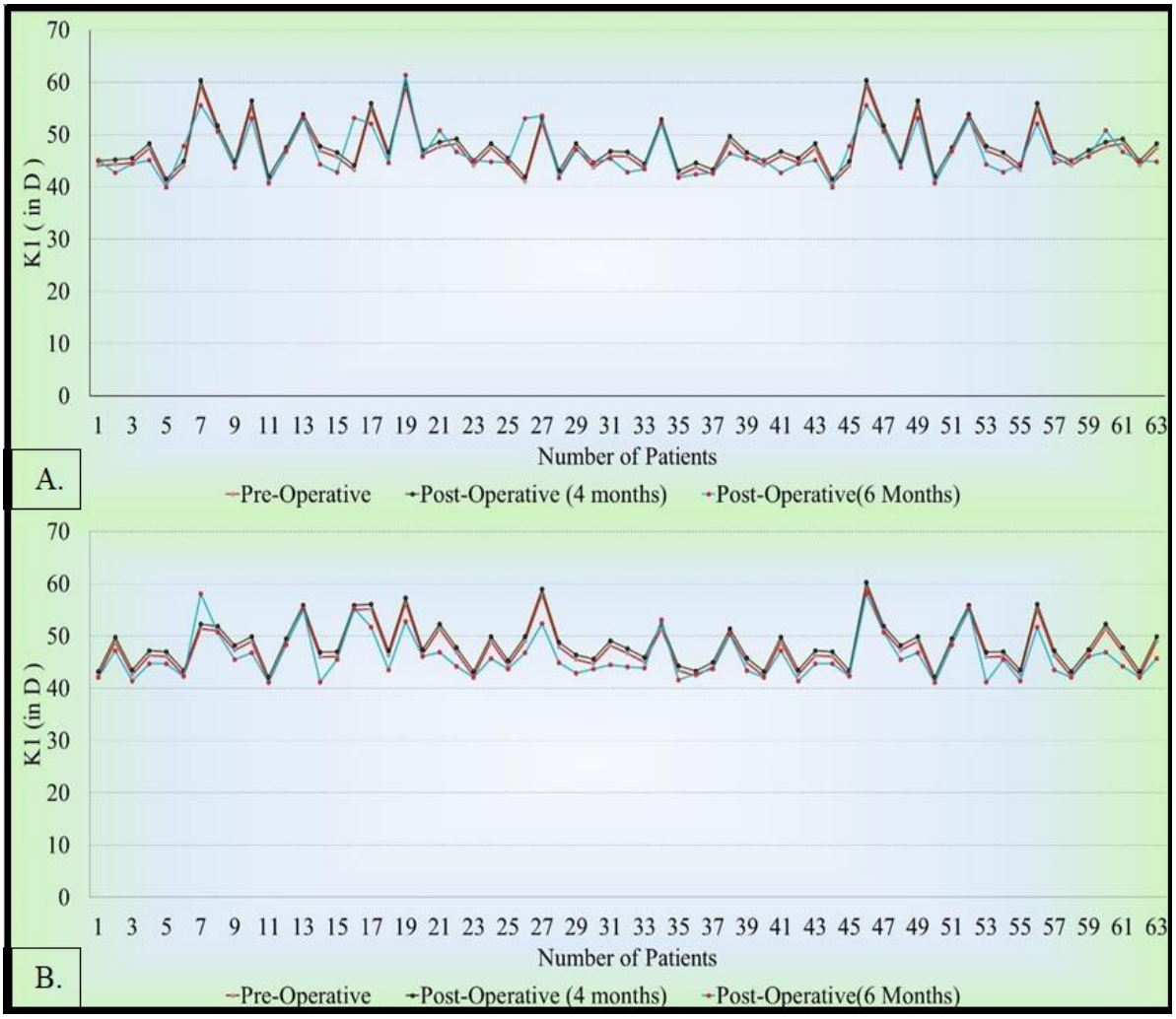

Figure 4. Line chart showing K1 of A. Right B. Left eye of the subjects enrolled in thestudy among different follow-up periods

Keratometry (K2)

Keratometry (K2) data for both right and left eyes are presented across different time points. Before the procedure, the mean K2 for the right eye was 50.35 ± 4.24 diopters, and for the left eye, it was 51.27 ± 5.01 diopters. Following the procedure, at the 4-month follow-up, there was an increase in K2, with the mean for the right eye increasing to 51.45 ± 4.24 diopters and for the left eye to 52.37 ± 5.01 diopters.

Table 4. K2 of the enrolled patients upon different periods of follow-up.

K2 (D)				
Follow-up Period	**Right**	**p-value***	**Left**	**p-value***
Pre-Operative (mean ±SD)	50.35 ± 4.24	**0.001**	51.27 ± 5.01	**<0.01**
Post-Operative 4 Month (mean ± SD)	51.45 ± 4.24		52.37 ± 5.01	
Post-Operative 6 Month (mean ± SD)	50.31 ± 5.70		49.81 ± 5.10	
The data is presented in mean ± SD.				

This trend reversed at the 6-month post-operative assessment, with the mean K2 for the right eye decreasing slightly to 50.31 ± 5.70 diopters and for the left eye to 49.81 ± 5.10 diopters. These findings suggest dynamic changes in corneal curvature following corneal collagen cross-linking, indicating potential alterations in corneal shape and refractive characteristicsover time after the procedure.

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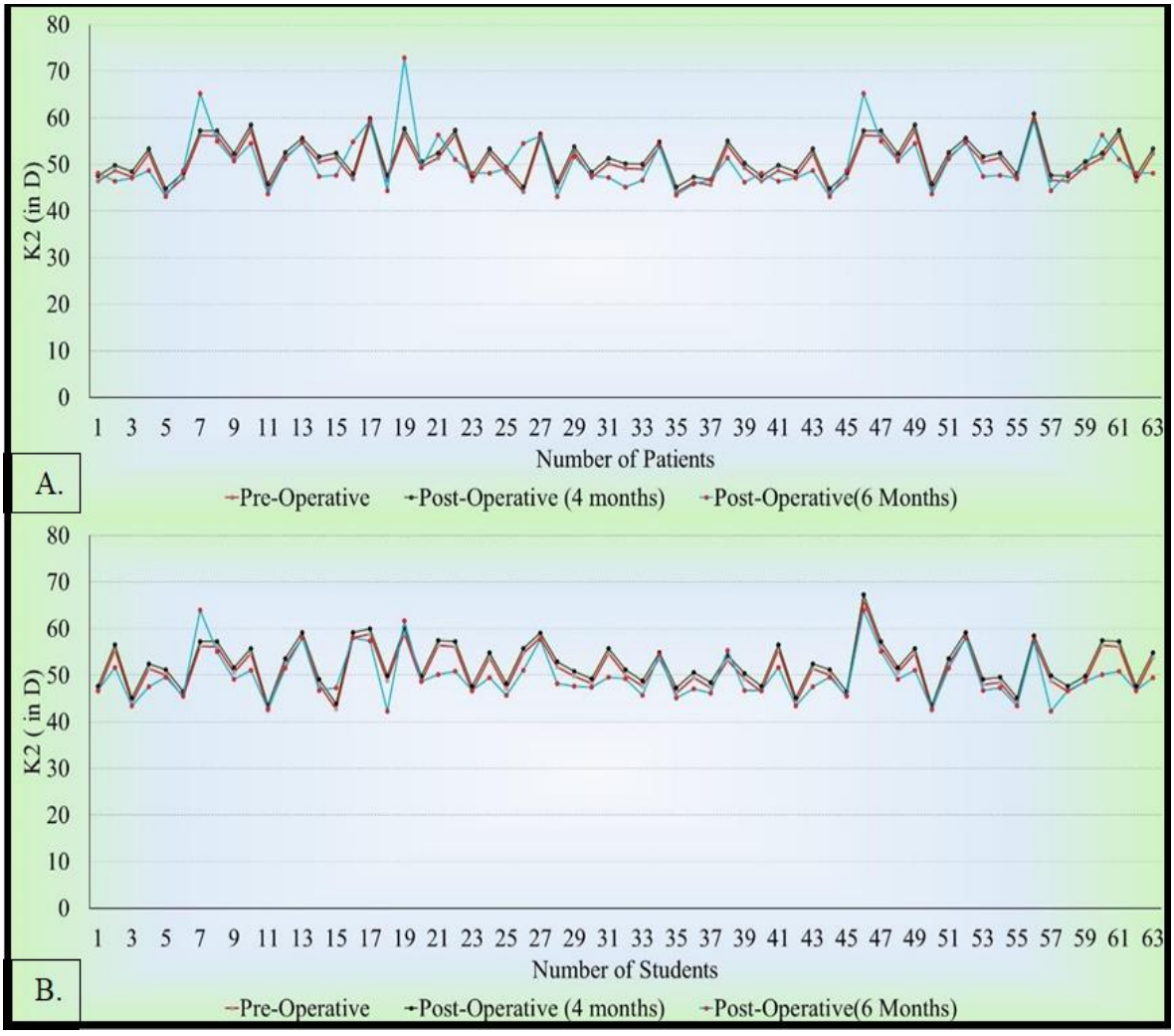

Figure 5. Line chart showing K2 of A. Right B. Left eye of the subjects enrolled in thestudy among different follow-up periods.

Average keratometry (AVG K)

Average keratometry (AVG K) data for both right and left eyes are presented across different time points. Before the procedure, the mean AVG K for the right eye was 48.65 ± 4.31 diopters, and for the left eye, it was 49.40 ± 4.58 diopters. Following the procedure, at the 4- month mark, there was an increase in AVG K, with the mean for the right eye increasing to 49.65 ± 4.31 diopters and for the left eye to 50.40 ± 4.58 diopters.

Table 5. AVG K of the enrolled patients upon different periods of follow-up.

AVG K (D)				
Follow-up Period	**Right**	**p-value***	**Left**	**p-value***
Pre-Operative (mean±SD)	48.65 ± 4.31	**<0.01**	49.40 ± 4.58	**<0.01**
Post-Operative 4 Month (mean ± SD)	49.65 ± 4.31		50.40 ± 4.58	
Post-Operative 6 Month (mean ± SD)	48.33 ± 5.09		47.78 ± 4.77	
The data is presented in mean ± SD.				

This trend reversed at the 6-month post-operative assessment, with the mean AVG K for the right eye decreasing slightly to 48.33 ± 5.09 diopters and for the left eye to 47.78 ± 4.77 diopters. These findings suggest dynamic changes in corneal curvature following corneal collagen cross-linking, indicating potential alterations in corneal shape and refractive characteristics over time after the procedure.

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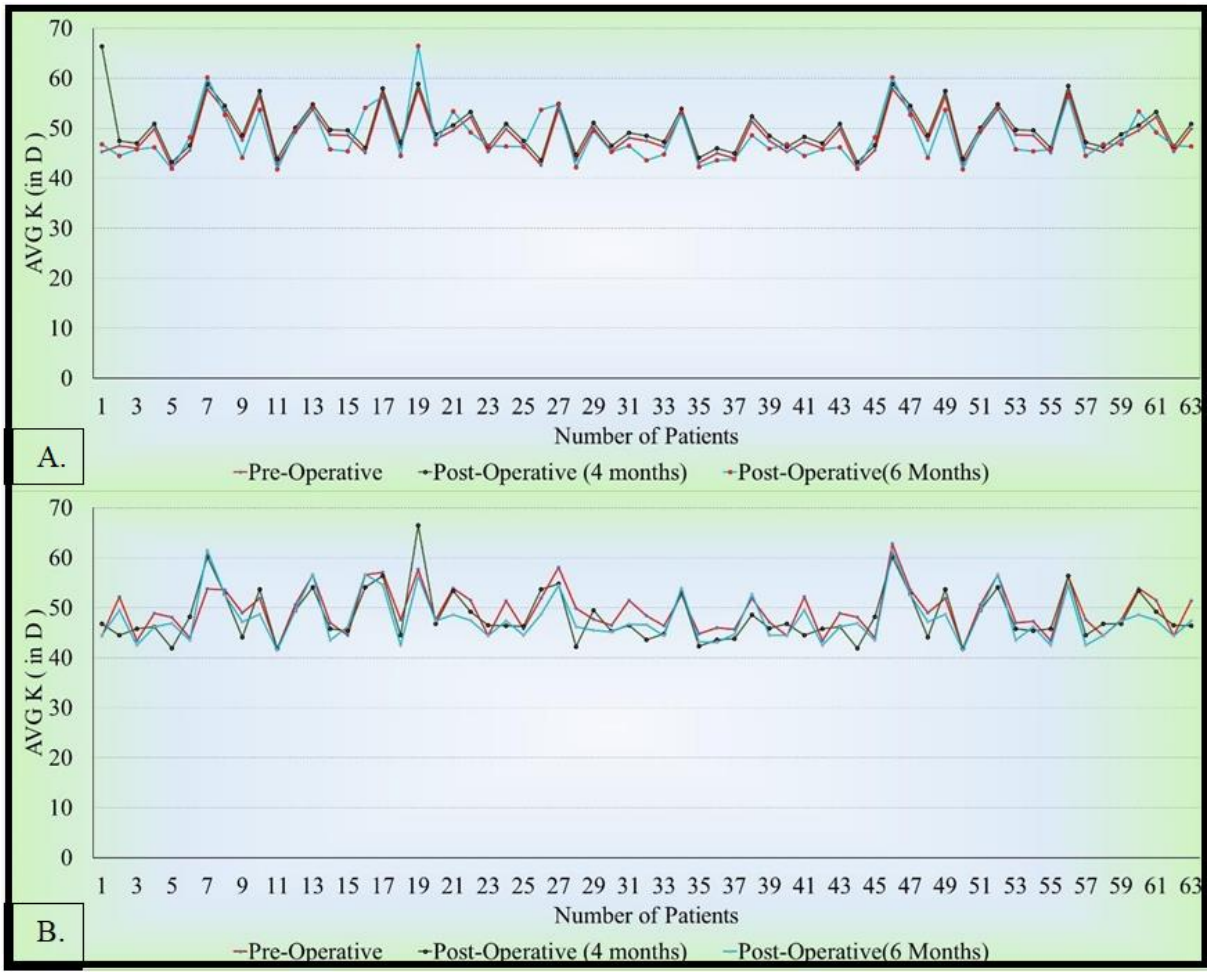

Figure 6. Line chart showing AVG K of A. Right B. Left eye of the subjects enrolled in thestudy among different follow-up periods.

DISCUSSION

The research aimed to assess how effective corneal collagen cross-linking (CXL) is as a treatment for keratoconus. The study group consisted mostly of males, and their average age was around 17.57 years. The analysis honed in on several key metrics: Best Corrected Visual Acuity (BCVA), which measures how well participants could see with corrective lenses; CCT(central corneal thickness) which gauges corneal thickness; and keratometry (K1, K2, AVG K), which evaluates corneal curvature. These parameters were tracked before and after the CXL procedure to understand any changes over time.

The results revealed significant improvements in BCVA following CXL, indicating better vision post-treatment. Additionally, there were observable fluctuations in corneal thickness and curvature, suggesting potential alterations in corneal biomechanics and shape. These changes were monitored at multiple intervals, such as the 4-month and 6-month follow-ups, providing a comprehensive view of how the eyes responded to the CXL procedure over time.

Moreover, a study by Ertan A. et.al 2008 show that the demographic breakdown highlighted a predominantly male group, shedding light on potential gender-related factors in keratoconus and its treatment outcomes. By focusing on these parameters and their evolution post-CXL, thestudy offers valuable insights into the efficacy of CXL as a therapeutic approach for managingkeratoconus and its impact on visual acuity, corneal thickness, and curvature dynamics [33].

The findings from the study revealed a significant improvement in Best Corrected Visual Acuity (BCVA) after the corneal collagen cross-linking (CXL) procedure. This improvement was consistently observed with a steady decrease in the mean BCVA values for both the rightand left eyes at the 4-month and 6-month follow-up assessments. This trend indicates that the CXL procedure had a positive impact on visual acuity, leading to better vision outcomes for individuals with keratoconus, as noted in the study by Ostadian, F. et.al (2021) [34].

As highlighted by Gassel CJ.et al (2021), The decrease in mean BCVA values signifies an enhancement in visual acuity post-CXL, suggesting that the procedure effectively addressed the visual challenges associated with keratoconus. This improvement is particularly noteworthy as it was observed across both eyes, indicating a bilateral benefit of the CXL intervention in improving vision [35].

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The steady nature of the improvement over the 4-month and 6-month follow-up periods suggests a sustained positive effect of CXL on visual acuity, rather than just a temporary or short-term improvement. This sustained improvement is crucial in the context of managing keratoconus, as it indicates the potential for long-term benefits in vision correction and enhancement for patients undergoing CXL treatment.

The pachymetry data, which measures corneal thickness, showed interesting patterns following the corneal collagen cross-linking (CXL) procedure. Initially, there was a decrease in corneal thickness observed at the 4-month follow-up. This decrease could be attributed to the collagen cross-linking process, which strengthens the corneal tissue and may lead to a more compactedor denser corneal structure.

However, the subsequent slight increase in corneal thickness noted at the 6-month assessment indicates a dynamic response in corneal biomechanics over time. This response suggests ongoing changes in how the cornea interacts with external forces and pressures. These changes may play a role in stabilizing the corneal shape and function, potentially contributing to improved vision outcomes post-CXL.

The dynamic alterations in corneal biomechanics are significant as they reflect the ongoing remodeling and adaptation processes within the cornea following the CXL procedure. These processes are essential for maintaining corneal integrity and stability, which are crucial for optimal visual function. By understanding these dynamic changes, clinicians can better assessthe long-term effects of CXL on corneal health and function in keratoconus patients, as highlighted by Knutsson. K. et.al (2023) [36].

The keratometry data, which assesses corneal curvature, displayed interesting fluctuations following the corneal collagen cross-linking (CXL) procedure. Initially, there was an increase in corneal curvature observed at the 4-month follow-up. This increase could be attributed to the effects of collagen cross-linking, which may initially cause some reshaping or alteration incorneal curvature.

However, what's particularly intriguing is the subsequent reversal towards pre-operative valuesnoted at the 6-month assessment. This reversal suggests a dynamic response in corneal shape and refractive characteristics over time post-CXL. Such changes indicate ongoing remodeling processes within the cornea as it adapts to the effects of the CXL procedure.

A study highlighted by Sadoughi, M. M. et.al (2015), These fluctuations in corneal curvature post-CXL signify potential modifications in corneal structure and stability. The initial increase followed by a return towards baseline values implies a temporary alteration in corneal shape that eventually stabilizes back towards its original configuration [37]. This dynamic response highlights the impact of CXL not just on corneal curvature but also on the overall structural integrity and stability of the cornea.

Understanding these changes in corneal curvature is crucial for assessing the long-term effects of CXL on corneal health and refractive outcomes in keratoconus patients. By monitoring these fluctuations, clinicians can better tailor post-operative care and follow-up to ensure optimal visual outcomes and corneal stability over time.

Study's comprehensive analysis and results strongly affirm the effectiveness of corneal collagen cross-linking (CXL) as a valuable therapeutic approach for managing keratoconus. The observed improvements in visual acuity post-CXL highlight its positive impact on addressing the visual challenges associated with keratoconus. These improvements are significant indicators of the procedure's success in enhancing the overall vision quality for patients, as noted in the study by Hersh, P. S. et.al (2011) [38].

Moreover, the study's exploration of corneal biomechanics and shape post-CXL reveals intriguing insights. The observed potential modifications in corneal biomechanics suggest that CXL not only improves visual acuity but also contributes to the stabilization and structural integrity of the cornea over time. This stabilization is crucial in managing keratoconus, as it can help prevent further progression of the condition and maintain long-term visual function.

The findings regarding corneal shape modifications post-CXL further emphasize the procedure's impact on corneal structure and stability. The observed fluctuations in corneal curvature followed by a return towards baseline values indicate a dynamic response within thecornea, showcasing its ability to adapt and stabilize post-CXL. These changes are essential considerations in understanding the long-term effects of CXL and its role in managing keratoconus effectively.

CONCLUSION

The conclusion drawn from the study's findings solidifies the position of corneal collagen cross-linking (CXL) as a fundamental and highly effective therapeutic approach for managing keratoconus. The evidence gathered not only showcases the notable improvements in visual acuity resulting from CXL but also delves deeper into understanding the intricate changes in corneal biomechanics and shape dynamics that occur post-procedure.

By elucidating these aspects, the study not only validates the clinical benefits of CXL in enhancing vision but also provides valuable insights into how the cornea responds and adapts to the treatment. These insights are pivotal in shaping optimized treatment strategies that can be tailored to individual patients, ensuring better long-term outcomes and management of keratoconus.

The comprehensive understanding gained from this research serves as a foundation foradvancing the field of keratoconus management. It opens avenues for

DOI: 10.69605/ijlbpr_13.8.2024.2

further exploration into refining CXL protocols, optimizing patient selection criteria, and developing personalized treatment plans that consider not just visual outcomes but also corneal health and stability.

Ultimately, the impact of these findings extends beyond the clinical realm, reaching into the realm of enhancing the quality of life for individuals affected by keratoconus. By offering a robust therapeutic modality that addresses both vision improvement and corneal health dynamics, CXL stands as a beacon of hope for better long-term outcomes and improved qualityof life for keratoconus patients worldwide.

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