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KERARING IMPLANTATION WITH FEMTOSECOND LASER IN KERATOCONUS TREATMENT AT DIFFERENT STAGES

KERATOKONUS TEDAVİSİNİN FARKLI EVRELERİNDE FEMTOSANİYE LAZERLE KERARING İMPLANTASYONU

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ABSTRACT

Objective: To investigate the reliability and effectiveness of femtosecond laser-assisted KeraRing (Mediphacos, Belo Horizonte, Brazil) implantation in treating keratoconus.

Methods: Intrastromal corneal ring segments (KeraRing, Mediphacos, Brazil) were implanted in 15 eyes of 14 patients unable to tolerate contact lenses. Femtosecond laser (Intralase, 60 Hz) was used for corneal tunnel creation. Based on the distribution of the ecstatic area on the cornea, dual segments were implanted in 9 eyes, while single segments were implanted in 6 eyes. Preoperative and postoperative uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), objective and subjective refraction, and topographic corneal curvature (K) values of the cases were compared using the Wilcoxon test.

Results: The median age of patients was 26 (range: 15-39) years, with a median postoperative follow-up period of 12 (range: 1-24 months). BCVA improved in all eyes during the follow-up period, increasing from a median of 0.4 (range: 0.15-0.6) to 0.5 (range: 0.15-1) ($p<0.001$). BCVA increased in 12 eyes, with a median of 0.1 (range: 0-0.4) ($p=0.003$), remained unchanged in 2 eyes, and decreased by 1 line in 1 eye. Subjective spherical refraction decreased from -3.02±3.8 to -1.43±2.7, and subjective cylindrical refraction decreased from -4.2±1.8 to -1.03±1.1 ($p<0.005$). Mean topographic astigmatism decreased from -5.03±2.0 D to -3.27±2.35 D ($p=0.012$), and the mean K value decreased from 52.6±4.7 D to 50.35±4.4 D ($p<0.005$). During the postoperative period, no complications were observed except for a slight migration of ring segments within the tunnel in one case.

Conclusion: Femtosecond laser-assisted intracorneal ring implantation is an effective and reliable method for visual outcomes in keratoconus.

Keywords: KeraRing, femtosecond laser, keratoconus

ÖZ

Amaç: Femtosaniye lazer destekli KeraRing (Mediphacos, Belo Horizonte, Brezilya) implantasyonunun keratokonus tedavisinde güvenilirliğini ve etkinliğini araştırmak.

Yöntem: Kontakt lens kullanamayan 14 hastanın 15 gözüne intrastromal korneal halka segmentleri (KeraRing, Mediphacos, Brezilya) implante edildi. Korneal tünel oluşturulması için femtosaniye lazer (Intralase, 60 Hz) kullanıldı. Korneadaki ektatik alanın dağılımına göre, 9 göze çift segment, 6 göze tek segment implante edildi. Olguların preoperatif ve postoperatif düzeltilmemiş görme keskinliği (UCVA), en iyi düzeltilmiş görme keskinliği (BCVA), objektif ve subjektif refraksiyon ile topografik korneal eğrilik (K) değerleri Wilcoxon testi kullanılarak karşılaştırıldı.

Bulgular: Hastaların ortalama yaşı 25±7.46 (aralık: 15-39) yıl olup, ortalama postoperatif takip süresi 10.8±7.37 (aralık: 1-24 ay) aydır. BCVA, takip süresi boyunca tüm gözlerde artmış, ortalama 0.12±0.1'den 0.38±0.24'e yükselmiştir ($p<0.001$). BCVA, 12 gözde ortalama 0.40±0.15'ten 0.55±0.23'e yükselmiş ($p=0.003$), 2 gözde değişmemiş ve 1 gözde 1 satır azalmıştır. Subjektif sferik refraksiyon -3.02±3.8'den -1.43±2.7'ye, subjektif silindirik refraksiyon ise -4.2±1.8'den -1.03±1.1'e düşmüştür ($p<0.005$). Ortalama topografik astigmatizma -5.03±2.0 D'den -3.27±2.35 D'ye ($p=0.012$) ve ortalama K değeri 52.6±4.7 D'den 50.35±4.4 D'ye düşmüştür ($p<0.005$). Postoperatif dönemde, bir vakada tünel içinde halka segmentlerinin hafif migrasyonu dışında komplikasyon gözlenmemiştir.

Sonuç: Femtosaniye lazer destekli intrakorneal halka implantasyonu, keratokonusta görsel sonuçlar açısından etkili ve güvenilir bir yöntemdir.

Anahtar Kelimeler: Keraring, femtosaniye lazer, keratokonus

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Introduction

Keratoconus is characterized as a progressive, asymmetric, bilateral corneal ectasia resulting from non-inflammatory thinning of the corneal stroma, leading to a conical shape of the cornea. Corneal thinning can cause a significant reduction in visual acuity due to irregular astigmatism, myopia, and corneal steepening. The visual management of keratoconus generally depends on the disease's severity. In advanced stages, penetrating keratoplasty is required to improve visual acuity due to severe irregular astigmatism, progressive stromal thinning, and apical stromal scar.[1,2] In mild to moderate stages, contact lenses are typically tried as initial treatment, with surgical options becoming necessary for patients intolerant to contact lens wear.[3] Corneal collagen cross-linking is a treatment option that slows the progression of the disease.[4]

Initially described by Barraquer in the mid-1950s for correcting myopia and astigmatism, corneal rings became an effective treatment option for stabilizing keratoconus and other ectasias.[4-6] Intracorneal ring segment implantation flattens the central corneal curvature in transparent corneas with moderate to advanced keratoconus, providing refractive improvement. Its reversible nature and preservation of the central cornea are significant advantages.[7-9] Additionally, it is suggested that progression to keratoplasty be delayed by providing biomechanical support to the ectatic cornea.[8,10] With the advancement of femtosecond laser technology, intracorneal ring implantation has become safer and is described as a minimally invasive technique [9,11] Three main types of intracorneal ring segments, produced from polymethyl methacrylate (PMMA) material and available in different geometric shapes and diameters, include Intacs segments (Addition Technology, CA, USA), Ferrara rings, and the KeraRing (Mediphacos, Belo Horizonte, Brazil) segments used in our study.[6,12]

Methods

Our study retrospectively reviewed the 15 eyes of 14 patients diagnosed with keratoconus. It underwent intracorneal ring segment (KeraRing) implantation by the same surgeon at the Haseki Training and Research Hospital Ophthalmology Clinic. All cases were patients with contact lens intolerance or inability to use contact lenses for various reasons. During the preoperative examination, all patients underwent assessments for uncorrected visual acuity, best corrected visual acuity, subjective and objective refraction, keratometry measurement, computerized corneal topography (Orbscan, Bausch and Lomb, Rochester, NY, USA), biomicroscopy for corneal wound formation and other pathologies, intraocular pressure measurement, and fundus examination. The eligibility criteria for intracorneal ring implantation included transparency of the central cornea, minimum corneal thickness of 400 µm at the site where the ring segment would be placed, absence of other ocular diseases, low visual acuity with glasses, and intolerance to contact lens wear or poor lens fit. Before surgical procedures, the type of ectasia was determined based on the steepest axis of corneal topography for each patient. The recommended segment thickness was determined using the chart provided in nomograms, based on the lowest pachymetry values obtained in the central 6 mm optical zone, and single or double-segment usage was planned. As a pre-tunneling medication, 0.5% proparacaine hydrochloride was instilled, and the periocular area was wiped with povidone-iodine. After the eye was sterilely draped, the central point of Purkinje reflex was marked. A disposable vacuum ring for the femtosecond laser was placed. Tunnel creation was performed using a femtosecond laser (Intra-lase, 60 Hz) at a depth of 80% of the thinnest para-central corneal thickness at a distance of 5-7 mm. The inner diameter of the tunnel was 4.7 mm, and the outer diameter was 5.8 mm. The entry incision was made perpendicular to the axis of topographic astigmatism with a length of 1.3 mm. Intracorneal ring segment implantation was performed under topical anesthesia by the same surgeon one to two hours after tunnel formation. A bandage contact lens was placed on the cornea, and the eye was covered with a bandage. Patients were started on artificial tear drops, nonsteroidal anti-inflammatory drops, and topical antibiotic drops on the day of surgery. After epithelialization of the incision site (within 1-2 days), the contact lens was removed, and topical steroid drops were initiated instead of nonsteroidal anti-inflammatory drops. Topical steroid drops were used thrice a day for 2 weeks and then tapered off gradually over 3 weeks. Topical antibiotic drops were used four times daily for 2 weeks and then discontinued. Artificial tears were used for an average of 3 weeks, depending on the epithelial status of the patients. Postoperative follow-up visits were scheduled for day 1, day 3, day 7, and month 1, and for patients with longer follow-up, at months 3, 6, and 12, and subsequently at 1-year intervals. Uncorrected and corrected visual acuity, objective and subjective refraction, keratometry values, corneal topography, and complications were recorded. Patients with a minimum follow-up period of 1 month were included in the study.

Statistical analyses were performed using SPSS version 13F software (SPSS Inc IBM, Armonk, NY, USA). The normality of variables was assessed using visual and analytical methods (Kolmogorov-Smirnov/Shapiro-Wilk tests). Preoperative and postoperative data were compared using the Wilcoxon test. P-values less than 0.05 were considered statistically significant.

Results

Of the patients, 8 (57.1%) were male and 6 (42.9%) were female, with a median age of 26 (range: 15-39 years). The median follow-up period was 12 (range: 1-24) months. The minimum follow-up period was 1 month, with only 2

patients having a follow-up of 1 month, 73.3% having at least 6 months, and 53.3% having at least 12 months (Table 1).

Table 1. The preoperative and postoperative ophthalmological findings

Patient No	Age	preop UCVA	postop UCVA	preop BCVA	postop BCVA	preop K ast (D)	postop K ast (D)	preop K min (D)	postop K min (D)	preop K max (D)	postop K max (D)	Follow-up time (month)
1	22	0.05	0.4	0.6	0.7	4.7	1.6	50.5	46.5	56.3	48.1	21
2	39	0.2	0.6	0.5	0.8	4.2	4.5	42.8	41.4	46.9	45.9	12
3	29	0.1	0.4	0.3	0.4	4.9	3.8	60.5	57.2	65.4	61	17
4	26	0.02	0.05	0.4	0.6	8.3	1.2	50.5	49.6	58.7	50.8	4
5	16	0.1	0.4	0.4	0.7	8.1	3.5	46.3	44.25	54.4	47.75	1
6	15	0.05	0.1	0.6	0.5	3.5	1.3	51.5	48.1	55	49.4	24
7	15	0.3	0.9	0.5	1	2.7	1.6	48.6	48	51.3	49.6	12
8	26	0.3	0.7	0.6	0.8	3	2.7	49.6	51	52.6	53.7	20
9	26	0.05	0.15	0.15	0.15	7.3	5.3	57.3	56.3	64.6	61.6	8
10	16	0.2	0.3	0.4	0.5	6.3	1.6	47.9	48.5	54.2	50.1	14
11	31	0.02	0.5	0.5	0.6	1.6	1.3	52.5	50	54.1	51.3	12
12	23	0.1	0.15	0.2	0.2	4	9.7	48.5	47.8	52.5	57.5	7
13	37	0.2	0.5	0.3	0.5	3.9	2.3	46.3	45.7	50.2	48	6
14	26	0.1	0.4	0.3	0.5	6.6	6.1	44.8	43.8	51.4	49.9	3
15	28	0.02	0.1	0.2	0.3	6.3	2.5	52.5	52.6	58.8	55.1	1

*Preop: Preoperative, postop: Postoperative; UCVA: Uncorrected visual acuity; BCVA: Best-corrected visual acuity (with glasses); K ast: Keratometric astigmatism value; K min: Minimum keratometry value; K max: Maximum keratometry value; D: diopter

During biomicroscopic examinations, Vogt's striae were observed in 2 patients, and signs related to atopy were present in 3 patients. Among those with signs of atopy, one patient had pannus in the superior cornea, and the other 2 had lid findings. Intraocular pressure measurements were standard in all patients, and no pathology was detected on fundus examination. For KeraRing implantation, 9 eyes received double segments, and 6 eyes received single segments based on the nomogram provided by the manufacturer and tailored to the ectatic area (Figure 1). Segment thickness ranged from 150 to 300 µm, and the arc length varied from 120° to 160°. Both eyes of one patient underwent KeraRing implantation. The incision site for tunneling was selected as the steepest axis topographically in all cases.

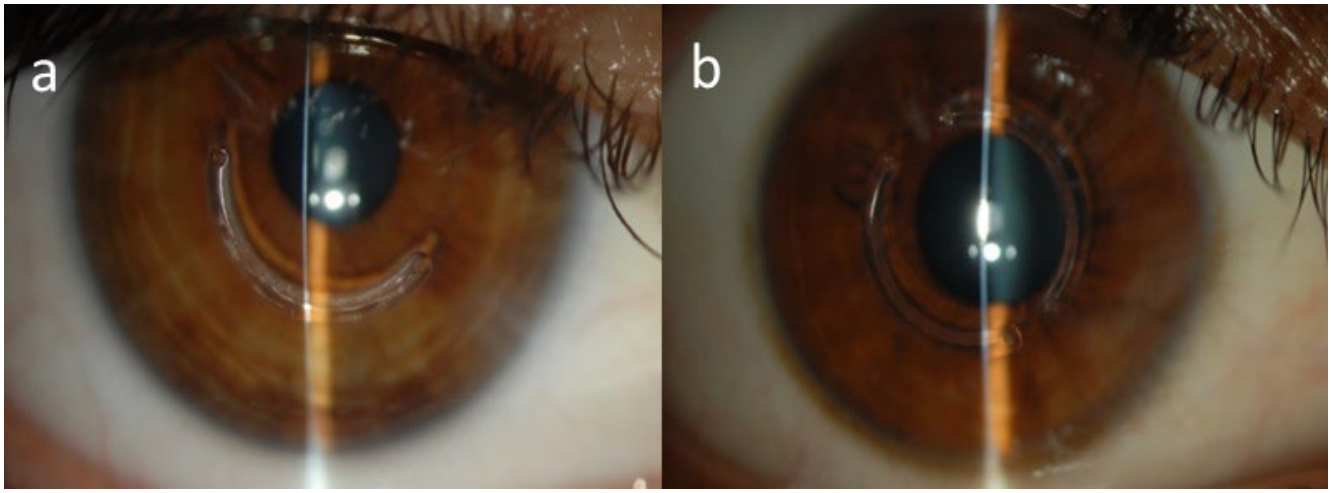

Figure 1. Biomicroscopic view of eyes implanted with a single ring segment (a) (left) and double ring segment (b) (right).

A statistically significant increase was observed in median uncorrected visual acuity (UCVA) (p<0.001). Increased UCVA was noted in all patients, rising from a preoperative median of 0.1 (range: 0.02-0.3) to a postoperative median of 0.4 (range: 0.15-0.6), with an average gain of 2.6 Snellen lines (Figure 2).

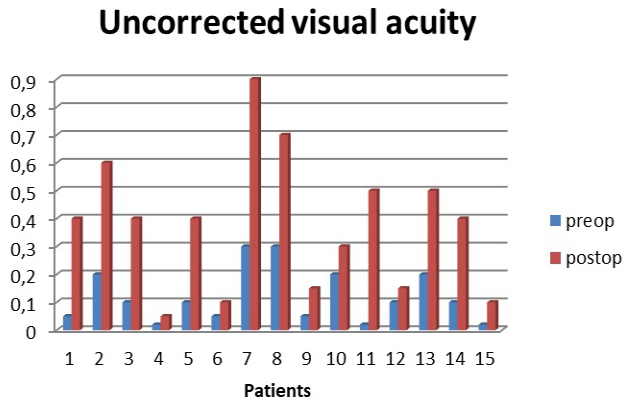

Figure 2. Change in uncorrected VA (visual acuity).

Statistically significant improvement was also observed in best-corrected visual acuity (BCVA) (p=0.003). While BCVA remained stable in two patients, a decrease of 1 Snellen line was observed in one patient. The median BCVA increased from a preoperative value of 0.4 (range: 0.15-0.6) to 0.5 (range: 0.15-1) postoperatively, with an average gain of 1.5 lines (Figure 3).

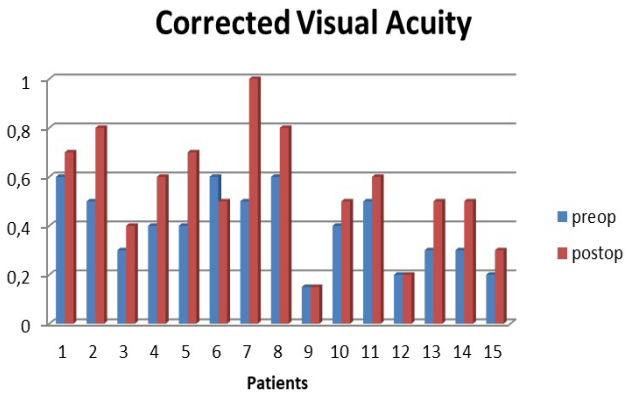

Figure 3. Change in best-corrected VA (visual acuity).

Postoperatively, the mean objective spherical refraction decreased from -4.67±5.4 to -2.88±4 (p=0.234). While it decreased in 10 eyes during follow-up, it remained stable in 2 eyes, and an increase in myopia was observed in 3 patients. The mean subjective spherical refraction decreased from -3.02±3.8 preoperatively to -1.43±2.7 postoperatively (p=0.114). Subjectively, spherical refraction decreased in 6 eyes, increased slightly in 4 eyes, and remained unchanged in 5 eyes. The mean objective cylindrical refraction decreased from -4.53±1.9 to -2.28±1.7 (p=0.002), and the mean subjective cylindrical refraction decreased from -4.20±1.8 to -1.03±1.1 (p=0.001). While objective cylindrical refraction decreased in 10 eyes and increased slightly in 5 eyes, subjective values decreased in all patients.

Following ring implantation, a decrease in minimum, maximum, and median corneal curvature (K value) and corneal flattening were observed (Table 2). The preoperative and postoperative corneal topographies of a patient are shown in Figure 4.

Table 2. The preoperative and postoperative topographic K values.

	preop (D) (median-min-max)	**postop (D) (median-min-max)**	**pre-post (D) (median-min-max)**	**p-value**
Kmax	54.10 (46.90 - 65.40)	51.30 (45.90 - 61.60)	3.0 (-5.0 - 8.2)	p=0,002*
Kmin	49.60 (42.80 - 60.50)	48.10 (41.40 - 57.20)	1.0 (-1.4 - 4.0)	p=0,008*
Kast	4.70 (1.60 - 8.30)	2.50 (1.20 - 9.70)	1.6 (-5.7 - 7.1)	p=0,012*
Kmean	51.10 (44.85 - 62.95)	49.30 (43.65 - 59.10)	1.8 (-2.15 - 6.1)	p=0,004*

*:statistically significant; Preop: Preoperative, postop: Postoperative; K ast: Keratometric astigmatism value; K min: Minimum keratometry value; K max: Maximum keratometry value; D: diopter

No progression was observed in any eye during the follow-up period, and no reoperations were required. One patient, who showed progression in one eye three months after KeraRing implantation and was planning pregnancy, was referred for collagen cross-linking treatment and received cross-linking in both eyes. One patient complained of glare, which spontaneously resolved within a few months. As a complication, a slight migration of ring segments into the tunnel was observed in one patient. The intervention was unnecessary as the migration direction was not towards the incision site.

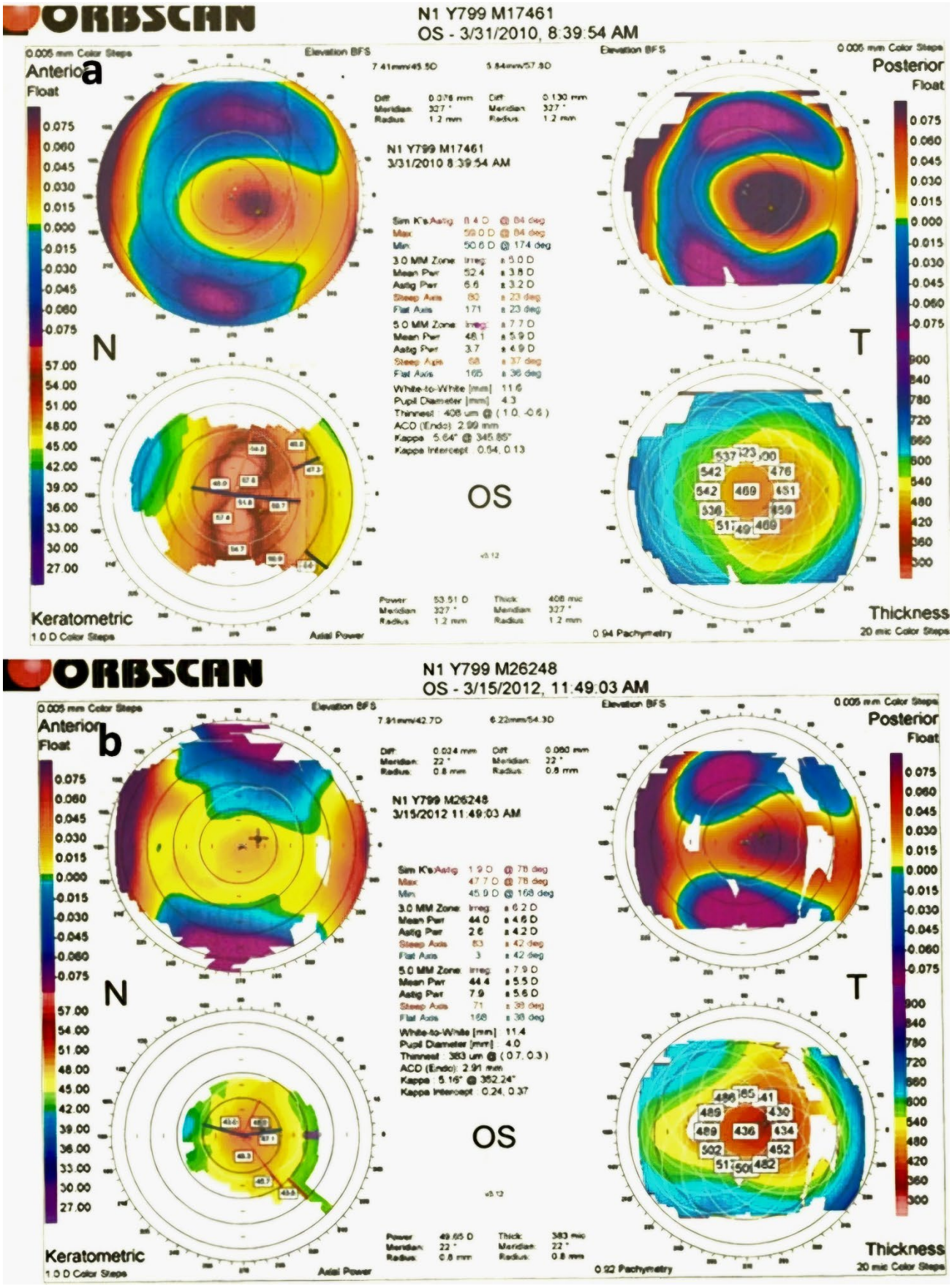

Figure 4. Corneal topography of a patient's preoperative (a) and postoperative (24th month) (b) images.

Discussion

In treating keratoconus, corneal ring implantation is a novel approach mainly applied before the indication for keratoplasty. Colin et al.[13] were the pioneering authors who reported a reduction in astigmatism associated with keratoconus and improved visual acuity using corneal ring (Intacs) segments. KeraRing, developed after Intacs, is a ring segment positioned closer to the optical center of the cornea with various design alternatives. The objective of KeraRing implantation is to reduce refractive errors in patients with contact lens intolerance or those unable to achieve optimal visual acuity with contact lenses/glasses, thereby improving uncorrected visual acuity (UCVA) and corrected distance visual acuity (CDVA) and enabling the use of contact lenses or glasses. Mainly designed for treating corneal ectasias, KeraRing aims to stabilize the cornea and delay the indication for keratoplasty.

Our study also demonstrated improvement in visual acuity, refractive values, and topographic features with KeraRing implantation in patients at different stages of keratoconus. Significant gains were observed with ring implantation in terms of UCVA and CDVA. A more tremendous increase was detected in UCVA compared to CDVA (100% vs. 93.3%). The postoperative mean UCVA was approximately equivalent to the preoperative mean CDVA. The average increase of 2.6 lines in UCVA and 1.5 lines in CDVA persisted without decrement during follow-up. Most patients included in the study experienced increased visual acuity from the first day following KeraRing implantation. The improvement in visual acuity post corneal ring implantation was attributed to corneal flattening and reduction in spherical and astigmatic refractive errors, as evidenced by changes in corneal curvature, topography, and refraction.

Corneal intrastromal rings were initially designed and utilized for the treatment of myopia. Patel et al.[14], in their investigation of the relationship between corneal asphericity and spherical aberrations in myopia correction using corneal intrastromal rings, suggested that the use of wide-diameter and thin rings would have less impact on corneal asphericity and thus would not increase spherical aberrations. According to the authors, a corneal intrastromal ring cannot correct myopia exceeding -4 D without significantly increasing spherical aberrations but may improve outcomes. Subsequently, numerous studies have been published regarding using corneal intrastromal rings for treating keratoconus, yielding successful outcomes. It is well-known that keratoconic corneas are more elastic compared to myopic corneas. Hence, more significant flattening is achieved in keratoconic corneas following ring implantation.

Different perspectives have been reported in the selection of corneal intrastromal ring segments. During their two-year follow-up study, Colin and Malet[15] utilized a standard nomogram, implanting two symmetric Intacs segments in 100 keratoconic patients. Boxer Wachler et al. established a ring segment nomogram based on spherical equivalent. For myopia up to -3.00 D, they implanted a thin segment superiorly and a thicker segment inferiorly. For myopia exceeding -3.00 D, they implanted a thin segment superiorly and a thicker segment inferiorly. This asymmetric ring implantation improved UCVA and CDVA and decreased irregular astigmatism. In both studies, the ring segments were implanted horizontally. Kanellopoulos et al.[16] modified the asymmetric segment placement nomogram, determining segment thicknesses to be implanted superiorly and inferiorly according to five different ranges of myopic values. In their study, the ring center was adjusted to the corneal center, and the position was set between 0.5 and 1.5 mm inferotemporal relative to the corneal geometric center. Colin published a nomogram based on spherical equivalent, corneal localization, and asymmetric astigmatism induced by keratoconus for Intacs segment selection.[13] Swanson, in a study where refractive correction was not specified, reported that in generally 90% of cases, the corneal surface was topographically flattened, curvature was flattened in all cases, and the cone shifted more centrally by placing a thin segment inferiorly and a thick segment superiorly.[17] According to these results, better outcomes were achieved with the asymmetric implantation of two different ring segments, resulting in the uneven flattening of two opposite corneal axes in irregular, asymmetric corneal surfaces and compared to Ferrara's symmetrically implanted corneal intrastromal rings, asymmetric ring implantation yielded more significant improvements in UCVA and CDVA. Conversely, Kwitko and Severo reported significantly better outcomes following symmetric ring implantation in centrally located keratoconic cases.[7] Utilizing KeraRing with different thicknesses and arc lengths asymmetrically allows for a personalized flattening effect on the cornea, thus achieving more effective outcomes. In line with this information, we aimed for effective refractive correction by using segments of different thicknesses and arc lengths based on our study's ecstatic area distribution on the cornea.

Various studies compare mechanical methods with femtosecond laser techniques for creating corneal tunnels. Rabinowitz reported no significant difference in clinical and topographic parameters between the two tunnel creation methods post-ring implantation. [18] Ertan et al.[19], in a retrospective study comparing the two methods, reported better outcomes in uncorrected and corrected visual acuities with tunnels created using the femtosecond laser method. However, this study had limitations that could affect the results: ring implantation was performed using different devices and nomograms at various centers. Finally, Kubaloğlu et al.[11] compared the mechanical method with the femtosecond laser method in a prospective randomized study involving 90 keratoconic patients' 100 eyes implanted with a 160-degree arc length KeraRing segment. They reported no significant difference between the two methods regarding visual and refractive outcomes. However, they observed more intraoperative and postoperative

complications using the mechanical method. Although the mechanical method is less expensive, the femtosecond laser method is reported to be faster, easier, and more comfortable for surgeons and patients. Another advantage of the femtosecond laser is its ability to create tunnels at the desired depth, especially in thin corneas. In our study, we performed tunnel creation using a femtosecond laser (Intralase, 60Hz). Although our sample size was small, the absence of intraoperative complications and the occurrence of only mild migration of ring segments within the tunnel in one patient during the postoperative period demonstrate the reliability of the femtosecond laser method.

Shabayek et al.[5] reported that corrected distance visual acuity (CDVA) was preserved or improved in approximately 95% of patients after KeraRing implantation. Coşkunseven et al. and Kubaloğlu et al. stated this rate as approximately 86% and 95%, respectively.[11,20] Pinero et al.[9] observed a significant increase in CDVA in their series. Alfonso et al.[21] published the results of KeraRing implantation in 219 keratoconic patients and found a substantial rise in CDVA in stage 1 and 2 keratoconus cases. However, there was no significant improvement in visual acuity in stage 3 keratoconus patients; nevertheless, approximately 85% of corrected distance visual acuity was preserved or improved. The same study observed a 3.2% rate of 2 or more lines loss in CDVA on the Snellen chart. The authors attributed this loss to irregular astigmatism that develops after ring implantation, as also mentioned by Ertan et al.[12] In our study, uncorrected visual acuity improved in all our patients (100%), and corrected CDVA improved or was preserved in 93.3% of patients. It was observed that uncorrected CDVA increased by at least 2 lines in 9 eyes (average 2.6 lines), while corrected CDVA increased by at least 2 lines in 7 eyes (average 1.5 lines). It was observed that CDVA decreased by 1 line in 1 patient and remained stable in 2 patients. Although staging was not performed due to the small number of cases, the results are similar to the high success rates reported in the literature.

Many studies have reported that KeraRing implantation is an effective method for correcting corneal shape and reducing astigmatism.[5,6,11,20,21] However, it has been noted that the extent to which astigmatism can be corrected in stage 3 keratoconus cannot be predicted. Pinero et al.[22] reported that the reason for poor outcomes in highly astigmatic eyes is the unpredictable and poor outcome of adding rings in these eyes with highly irregularly arranged corneal lamellae. Our study observed significant K values and astigmatism reductions in moderate and advanced keratoconus patients. Particularly in one patient with advanced keratoconus who had previously waited for keratoplasty at another center, an increase of 3 lines in uncorrected CDVA and 1 line in corrected CDVA was achieved with KeraRing implantation, and it was observed that the average K value decreased from 62.95 D preoperatively to 59.1 D postoperatively.

There has yet to be a consensus on which localization is better for corneal incision placement. Different incision sites have been described in the literature, including temporal position, superior position (12 o'clock), positive cylinder axis not deviating more than 90° from the topographic axis, temporal and 1 o'clock positions above the horizontal axis, and perpendicular to the topographic axis. Theoretically, as most surgeons apply, the ideal position should be on the steepest corneal axis, as this type of incision reduces corneal power along the steepest axis and yields flat keratometric values. However, a significant reduction in astigmatism has been observed with incisions at other locations. In our study, we selected and applied the incision site topographically as the steepest corneal axis, like many surgeons. Considering the more significant difference in Kmax values, we believe the incision on the steep axis also has a relaxing effect.

High degrees of ametropia may occur after KeraRing implantation. This ametropia can be corrected with glasses or contact lenses. In recent years, successful results have been reported in correcting ametropia and residual astigmatism with posterior chamber toric intraocular lens implantation after ring implantation. Although some of our patients developed ametropia, no significant improvement in vision with glasses was observed in these patients. As the follow-up periods were short, none of our patients underwent intraocular lens implantation.

As mentioned earlier, corneal ring implantation does not prevent the progression of keratoconus. Particularly in keratoconic patients showing rapid progression, an increase in mean K values has been observed 6-36 months after ring implantation. This is because ring implantation does not address the structural problem of weakened collagen structure in the disease. Considering the successful visual and refractive outcomes of corneal rings, combined treatment methods have begun to be attempted. With collagen cross-linking therapy, the corneal biomechanical rigidity increases 4-5 times, and the collagen fibril diameter increases. This promotes structural improvement in keratoconus, thus preventing progression. In their studies, Chan et al.[23] reported that combined Intacs implantation with cross-linking increased the corneal flattening effect of Intacs. Combined corneal ring implantation with collagen cross-linking can be used to maintain stability when progression occurs after ring implantation or to maintain the flattening effect of the ring. Our study observed no progression in any patient during the follow-up period. Only one patient was referred for cross-linking therapy due to progression starting in the other eye.

In a study comparing deep anterior lamellar keratoplasty (DALK) and intrastromal corneal ring segments in advanced keratoconus, the authors compared 66 eyes regarding visual, refractive, and topographic K values.[24] They found improved visual acuity and refractive values in advanced keratoconus with DALK. Additionally, they reported that corneal ring segments were an alternative treatment method with fewer complications and sufficient results. [24] Corneal ring implantation should be attempted before keratoplasty in advanced keratoconus

without apical scarring and adequate corneal thickness. [24]

Our study has some limitations. Firstly, it does not include a control group. Selecting an appropriate control group for diseases like this is difficult due to variations in the progression levels of patients, and the small number of patients contributed to this. Moreover, selecting the other eye as the control group will not eliminate the problem because the disease progresses asymmetrically, and each eye's progression rate may differ. Another area for improvement in our study is the small number of patients and, therefore, the inability to group them by stages. Additionally, the follow-up periods were relatively short, especially for some patients. Despite these limitations, our study has shown that corneal ring implantation successfully rehabilitates keratoconus patients who are intolerant to contact lenses or unable to use contact lenses for various reasons. KeraRing are intracorneal ring segments developed for the optical treatment of keratoconus. When used in suitable patients for ring implantation, they significantly improve visual acuity, refractive, keratometric, and topographic outcomes. Although they do not prevent the progression of the disease, obtaining satisfactory visual outcomes and delaying keratoplasty are essential advantages. In our patients, there was a significant increase in both uncorrected ($p<0.001$) and corrected ($p=0.003$) best-corrected visual acuities. This increase is attributed to the corneal flattening effect and the reduction of corneal astigmatism by the rings. A significant decrease in astigmatic refractive values ($p=0.002$) was observed, while the reduction in myopic refractive values ($p=0.234$) was not significant. When looking at topographic characteristics, there was a substantial decrease in median K ast, K min, K max, and K median values due to the corneal flattening effect of KeraRing ($p=0.012$, $p=0.008$, $p=0.002$, $p=0.004$, respectively). No complications were observed except for one patient who migrated the ring segment into the tunnel. In conclusion, KeraRing implantation in keratoconus patients using a femtosecond laser is a safe, low-complication rate, easily applicable, and optically successful method.

Compliance with Ethical Standards

This study was approved by the Institutional Review Board and Ethics Committee of Haseki Training and Research Hospital (date: 23.05.2024 no.31-2024). The methods complied with the principles of the Helsinki Declaration.

Conflict of Interest

The author declares no conflicts of interest.

Author Contribution

All the authors equally contributed to this work.

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None

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