Risk factors for ectasia after laser in situ keratomileusis in an Egyptian population sample

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Purpose
The aim of this study was to determine the prevalence and risk factors of post-laser in situ keratomileusis (post-LASIK) ectasia in an Egyptian population sample.
Design
This is a retrospective case–control study.
Patients and methods
The study included 44 patients, who were classified into two groups. The first group (post-LASIK ectasia) included 31 eyes (18 patients) and the second group (LASIK without complications) included 52 eyes (26 patients). The comparison between the two groups included the pre-LASIK refractive error, corrected distance visual acuity (CDVA), corneal curvature, corneal thickness, corneal elevations, ectasia risk scoring, flap thickness, and residual stroma after LASIK. We also evaluated the changes that occurred in patients with ectasia in comparison to their pre-LASIK parameters.
Results
The prevalence of post-LASIK ectasia was 0.22%. The degree of myopia, astigmatism, maximum keratometry reading (K-max), ectasia risk scoring, and flap lift for retreatment were significantly higher in the ectasia group compared with the control group (P=0.041, 0.006, 0.016, 0.038, and 0.017, respectively), while the CDVA and residual stroma after LASIK were significantly less in the ectasia group (P=0.039 and 0.003, respectively). There was a statistically significant increase in astigmatism and change in its type and increased K-max and corneal elevations after ectasia.
Conclusions
The degree of myopia, astigmatism, CDVA, K-max, ectasia risk scoring, residual stroma after LASIK, and retreatment are risk factors for ectasia development.

Keywords:
corneal ectasia, laser in situ keratomileusis complications, laser in situ keratomileusis, post-laser in situ keratomileusis ectasia

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Introduction

Vision impairment is of great importance for the quality of life and for the socioeconomic and public health status of societies and countries [1]. Corrective refractive surgery, especially laser in situ keratomileusis (LASIK), is one of the most frequently used ophthalmic procedures globally due to its safety, efficacy, and quick visual recovery [2,3], with an estimated 1.5 million annual procedures performed worldwide [4].

While effective means have emerged to manage several LASIK complications, others remain patient to investigation [5,6]. Post-LASIK ectasia is a visually debilitating complication of an elective refractive procedure [7]. It is a structural abnormality of the cornea and is first identified with changes in corneal topography [8]. Patients with keratoconus (KC) and other ectatic disorders, specifically with subclinical disease, are at high risk for iatrogenic ectasia development after the surgical procedure [9,10].

Insight into the risk factors for ectasia may prevent potentially ectatic eyes from undergoing refractive surgery [11]. Detecting the risk of ectasia remains challenging in the evaluation of potential refractive surgery candidates [12,13]. Thus, this study was performed to determine the prevalence and risk factors of post-LASIK ectasia in an Egyptian population sample.

Patients and methods

This is a retrospective, case–control study, which was approved by the Institutional Review Board of the Faculty of Medicine, Assiut University (approval number 17100605, dated 18/11/2018). This is a retrospective study. Therefore, consent statement has been waived. The study adhered to the Declaration of Helsinki.

The study included post-LASIK ectasia cases that occurred over 5 years at Alforsan and Elnour Private Eye Centres. They were compared with a sample of patients who underwent successful LASIK (without ectasia). The sample size was calculated using Epi Info, (version 7.2.5, 2021 (Centers for Disease Control and Prevention, Atlanta, Georgia, USA)). Based on a previous study of a risk assessment for ectasia after corneal refractive surgery [14] (odds ratio 7.6, power 80%, confidence level of 95%), the sample was calculated as 23 eyes and 23 controls. Two cases and two controls were added for dropouts with a final sample size of 50 eyes.

All patients diagnosed with ectasia after LASIK between 10-9-2016 and 7-1-2021 were included. The diagnosis of ectasia was defined as inferior topographic steepening of 5 D or more compared with the immediate postoperative appearance, loss of two or more Snellen's lines of uncorrected visual acuity, and a change in manifest refraction of 2 or more D in either sphere or cylinder [8,9,15]. Controls were selected using randomized simple selection, considering that they had undergone uneventful LASIK in the past 5 years. Patients were excluded if they exhibited pre-LASIK data as follows: cornea thinner than 480 μm, estimated residual stromal bed (RSB) of less than 280 μm, corneal irregularities comparable to KC, posterior corneal surface elevation evaluated at the thinnest point of more than +15 μm in myopia and more than +25 μm in hyperopia, estimated postoperative keratometry readings of less than 34.0 D or higher than 49.0 D, preoperative corneal opacities influencing the visual acuity, clinically significant cataract, progressive retinal disorders, history of previous ocular trauma, or ocular surgeries other than the LASIK procedure.

All candidates of LASIK routinely underwent comprehensive preoperative screening including manifest and cycloplegic refraction (sphere and cylinder), slit-lamp biomicroscopy examination, intraocular pressure measurement, dilated fundus examination, corneal thickness evaluated with rotating Scheimpflug techniques, corneal tomography, keratometry, and estimated RSB thickness using the Oculus Pentacam (Pentacam HR, V.1.15r4 n7; Oculus Optikgeräte GmbH, Wetzlar, Germany). The patients were interviewed regarding any family history of KC, history of contact lens use, eye rubbing, the nature of any progressive visual loss, and history of any systemic disease or dysfunction. The patients were also evaluated regarding ectasia risk scoring, which takes into account the RSB thickness, preoperative corneal thickness, preoperative corneal topography, age at time of surgery, and manifest refractive correction [14].

The surgical data included the excimer laser model, microkeratome model, intended flap diameter and thickness, ablation diameter, and ablation depth. All corneal flaps were created using the mechanical microkeratome Moria M2 microkeratome (Moria, Antony, France), while stromal ablations were performed using WaveLight Allegretto Wave Eye-Q 400 Hz (Alcon Laboratories Inc., Fort Worth, Texas, USA).

Postoperatively, the routine follow-up was done at day 1, after 1 month, 3 months, and 1 year to examine flap healing, interface integrity, and visual recovery. Data were gathered during a comprehensive ophthalmologic examination, including the time between diagnosis of corneal ectasia and the last LASIK procedure, corrected distance visual acuity (CDVA), manifest refraction (sphere and cylinder), precise slit-lamp examination, and corneal topography. Corneal astigmatism was considered significant if it was more than 1 D.

Statistical analysis

The data were verified and analyzed using the Statistical Package for Social Sciences (SPSS), version 24 (SPSS Inc., Chicago, Illinois, USA). The descriptive statistics included mean, SD, median, interquartile range, and percentage. χ^2/Fisher's exact test was used to compare the difference in the distribution of frequencies. Student's t test and Mann–Whitney U test were used to test the mean/median differences for continuous variables between groups (parametric and nonparametric). Paired samples t test and related-samples Wilcoxon signed rank test were used to compare the mean/median on repeated measures. Statistical significance was considered when the P value was less than 0.05.

Results

The ectasia group included 31 eyes (of 18 patients) who presented with post-LASIK ectasia during the study period. They underwent LASIK procedure between

8-12-2013 and 4-11-2017. The control group included 52 eyes (of 26 patients) which underwent uneventful LASIK, randomly selected from the same period as the ectasia patients.

The prevalence of post-LASIK ectasia was 0.22% (31 out of 13 883 eyes) from 18 out of 7556 patients. There was no statistically significant difference between the ectasia group and the uneventful LASIK group regarding age and sex (P>0.05, Table 1).

The median spherical equivalent of refractive error was significantly higher in the ectasia group (−5.73±2.3 D, P=0.041), while the preoperative CDVA was significantly better in the control group (median 0 [0.1] LogMar, P=0.039). Corneal astigmatism was significantly higher in the ectasia group (1.61±0.9 D, P=0.006), although the type of astigmatism was not significantly different between the two groups (P=0.572). The presence of significant corneal astigmatism (>1 D) was significantly higher in the ectasia group (67.7%) than in the control group (46.2%, P=0.046) (Table 2).

Regarding the corneal curvature and thickness, the only significant difference between the two groups was the mean maximum keratometry reading (K-max) of the anterior corneal surface. It was significantly higher in the ectasia group (45.82±1.8 D) than in the control group (44.89±1.6 D) (P=0.016, Table 3).

Regarding corneal elevations and ectasia risk scoring, the corneal elevation for the front and back surfaces were not statistically significantly different between the two study groups (median front=3 [2] and 3 [3] and median back=5.5 [4] and 7 [7] for the control and ectasia groups, respectively, P=0.79 and 0.166, respectively). There was also no statistically significant difference between the back and front elevation (median 3 [2] for the control group and 4 [3] for the ectasia group, P=0.118). The ectasia group had a higher percentage of high-risk ectasia scoring (29%) than the control group (7.7%), but the low-risk scoring of ectasia was higher in the control group (69.2%) than in the ectasia group (51.6%) (P=0.038) (Table 4).

The corneal flap thickness was not statistically significantly different between the two groups (median 110 [20] μm for the control group and 120 [20] μm for the ectasia group, P=0.073). The RSB was significantly less in the ectasia group (median 314 [38] μm) than in the control group (median 338.5 [47] μm) (P=0.003). The percentage of RSB to corneal thickness at the thinnest location was significantly different (median 64 [9.5]% for the control group and 60 [6.5]% for the ectasia group, P=0.005). The

Table 1 Age and sex distribution

Parameters	Control (N=26)	Ectasia (N=18)	P
Age (years)	28.65±5.8	27.92±5.6	0.679(a)
Sex [n (%)]			
Male	5 (19.2)	6 (33.3)	0.113(b)
Female	21 (80.8)	12 (66.7)	

[a]Student's t test was used to compare the mean differences between groups. [b]χ^2 test was used to compare proportions between groups.

Table 2 Differences in visual acuity and refractive errors between groups

Parameters	Control (N=52)	Ectasia (N=31)	P
SE			
Mean±SD	−4.80±2.8	−5.73±2.3	0.041(a)*
Median (IQR)	−4 (3)	−6 (4)	
CDVA (logMAR)			
Mean±SD	0.07±0.01	0.13±0.02	0.039(b)*
Median (IQR)	0 (0.1)	0.05 (0.2)	
Corneal astigmatism			
Mean±SD	1.05±0.7	1.61±0.9	0.006(a)*
Median (IQR)	0.8 (0.2)	1.4 (0.4)	
Significant astigmatism >1 D [n (%)]			
No	28 (53.8)	10 (32.3)	0.046(c)*
Yes	24 (46.2)	21 (67.7)	
Type of astigmatism [n (%)]			
With the rule	19 (79.2)	17 (81)	
Against the rule	3 (12.5)	1 (4.8)	0.572(c)
Oblique	2 (8.3)	3 (14.3)	

CDVA, corrected distance visual acuity; IQR, interquartile range; SE, spherical equivalent. [a]Mann–Whitney U test was used to compare the median difference between groups. [b]Student's t test was used to compare the mean difference between groups. [c]χ^2 test was used to compare proportions between groups. *Statistically significant.

Table 3 Corneal curvature and thickness difference between groups

Parameters	Control (N=52)	Ectasia (N=31)	P(a)
K-max			
Mean±SD	44.89±1.6	45.82±1.8	0.016*
Median (IQR)	45 (2)	45.5 (2)	
Mean anterior K			
Mean±SD	43.93±1.5	44.33±1.3	0.220
Median (IQR)	44 (1.7)	44.3 (1.4)	
Mean posterior K			
Mean±SD	−6.28±0.3	−6.37±0.2	0.147
Median (IQR)	−6.2 (0.5)	−6.5 (0.3)	
T at TL			
Mean±SD	532.92±27.5	526.74±22.9	0.275
Median (IQR)	534 (38)	528 (36)	

IQR, interquartile range; K, keratometry reading; K-max, maximum keratometry reading; T at TL, thickness at the thinnest corneal location. [a]Student's t test was used to compare the mean differences between groups. *Statistically significant.

Table 4 Corneal elevation and ectasia risk scoring differences between groups

Parameters	Control (*N*=52)	Ectasia (*N*=31)	*P*
F/BFS			
Mean±SD	3.38±1.9	3.06±2.1	0.790(a)
Median (IQR)	3 (2)	3 (3)	
B/BFS			
Mean±SD	5.75±4.5	7.32±5.9	0.166(a)
Median (IQR)	5.5 (4)	7 (7)	
B-F			
Mean±SD	2.37±2.1	4.26±3.6	0.118(a)
Median (IQR)	3 (2)	4 (3)	
Ectasia risk scoring [*n* (%)]			
Low	36 (69.2)	16 (51.6)	
Moderate	12 (23.1)	6 (19.4)	0.038(b)*
High	4 (7.7)	9 (29)	

B/BFS, back elevation at best fit sphere map; B-F, back to front elevation difference; F/BFS, front elevation at best fit sphere map; IQR, interquartile range. [a]Mann–Whitney *U* test was used to compare the median difference between groups. [b]χ^2 test was used to compare proportions between groups. *Statistically significant.

Table 5 Flap-related data differences between groups

Parameters	Control (*N*=52)	Ectasia (*N*=31)	*P*
Flap thickness (μm)			
Mean±SD	116.35±9.2	120.32±9.8	0.073(a)
Median (IQR)	110 (20)	120 (20)	
Bed (μm)			
Mean±SD	343.08±33.2	320.94±31.2.9	0.003(a)*
Median (IQR)	338.5 (47)	314 (38)	
Bed/corneal thickness %			
Mean±SD	64.37±5.2	60.92±5.1	0.005(a)*
Median (IQR)	64 (9.5)	60 (6.5)	
Complications [*n* (%)]			
No	52 (100)	(87.1)	0.017(b)*
Yes	0	4 (12.9)	

IQR, Interquartile range. [a]Mann–Whitney *U* test was used to compare the median difference between groups. [b]Fisher's exact test was used to compare proportions between groups. *Statistically significant.

Table 6 Effect of treatment on astigmatism in the ectasia group

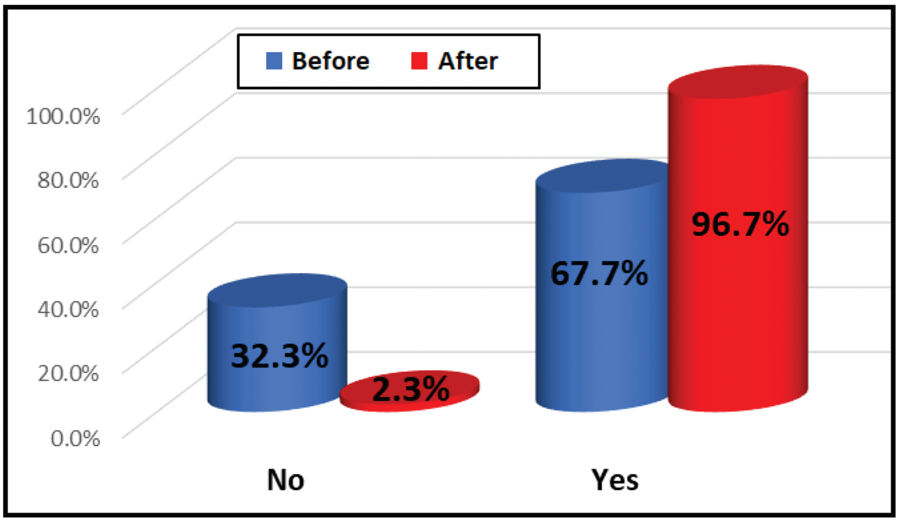
Parameters	Before	After	*P*
Corneal astigmatism (K2–K1)			
Mean±SD	1.61±0.9	2.79±1.4	<0.001(a)*
Median (IQR)	1.4 (0.4)	2.8 (1.2)	
Significant astigmatism [*n* (%)]			
No	10 (32.3)	1 (2.3)	<0.001(b)*
Yes	21 (67.7)	30 (96.7)	
Type of astigmatism [*n* (%)]			
With the rule	17 (81)	6 (25.8)	
Against the rule	1 (4.8)	9 (29)	<0.001(b)*
Oblique	3 (14.3)	14 (45.2)	

IQR, interquartile range; K1, flat keratometric reading; K2, steep keratometric reading. [a]Wilcoxon signed-rank related-samples test was used to compare the median difference between groups. [b]McNemar test was used to compare proportions on repeated measures. *Statistically significant.

ectasia group showed a significantly higher rate of complications after LASIK (12.9%) than the control group (0%) (*P*=0.017) (Table 5). Three eyes of two patients showed undercorrection and required LASIK enhancement after lifting the old flap. One case with an incomplete flap required another flap creation to perform LASIK 1 month after the first procedure.

In the ectasia group, the postoperative corneal astigmatism (K2–K1) was significantly higher (median 2.8 [1.2] D) than that before performing the LASIK procedure (median 1.4 [0.4] D) in these patients (*P*<0.001). Significant corneal astigmatism (>1 D) before LASIK in the ectasia group was reported in 67.7% of the patients, which was significantly increased to 96.7% after ectasia (*P*<0.001, Table 6 and Fig. 1). The type of astigmatism before the LASIK procedure also changed significantly after ectasia development

Figure 1



Rate of astigmatism before LASIK compared with after LASIK treatment among the ectasia group. LASIK, laser in situ keratomileusis.

(P<0.001). Astigmatism was with rule in 81% of the cases before LASIK in the ectasia group and decreased to 25.8% after the development of ectasia with an increase in the percentage of oblique astigmatism (45.2%) and against the rule astigmatism (29%) (Table 6 and Fig. 2).

The maximum corneal curvature (K-max) showed a significant increase after developing ectasia (51.67±6.1 D) compared with before LASIK (45.82±1.8 D) in the ectasia group (P<0.001). In addition, the mean corneal curvature of the posterior surface showed a significant increase after ectasia (−7.03±0.8 D) in comparison to that before LASIK (−6.37±0.2 D) (P<0.001) (Table 7).

The corneal elevation for the front surface was significantly higher after ectasia (median 14 [12]) than before LASIK (median 3 [3]) (P<0.001). The corneal elevation for the back surface also showed a significant increase after ectasia (median 40 [30]) than before LASIK [median 7 (7)] (P<0.001). The difference between the back and front elevation significantly increased after ectasia (median 24 [20]) than before LASIK (median 4 [3]) (P<0.001) (Table 8).

Table 7 Effect of treatment on corneal curvature among the ectasia group

Parameters	Before	After	P(a)
K-max			
Mean±SD	45.82±1.8	51.67±6.1	<0.001*
Median (IQR)	45.5 (2)	51 (6)	
Mean anterior K			
Mean±SD	44.33±1.3	44.19±3.9	0.846
Median (IQR)	44.3 (1.4)	44 (4.5)	
Mean posterior K			
Mean±SD	−6.37±0.2	−7.03±0.8	<0.001*
Median (IQR)	−6.5 (0.3)	−6.9 (0.8)	

IQR, interquartile range; K-max, maximum keratometry reading; K, keratometric reading. [a]Paired sample *t* test was used to compare the mean differences between groups. *Statistically significant.

Discussion

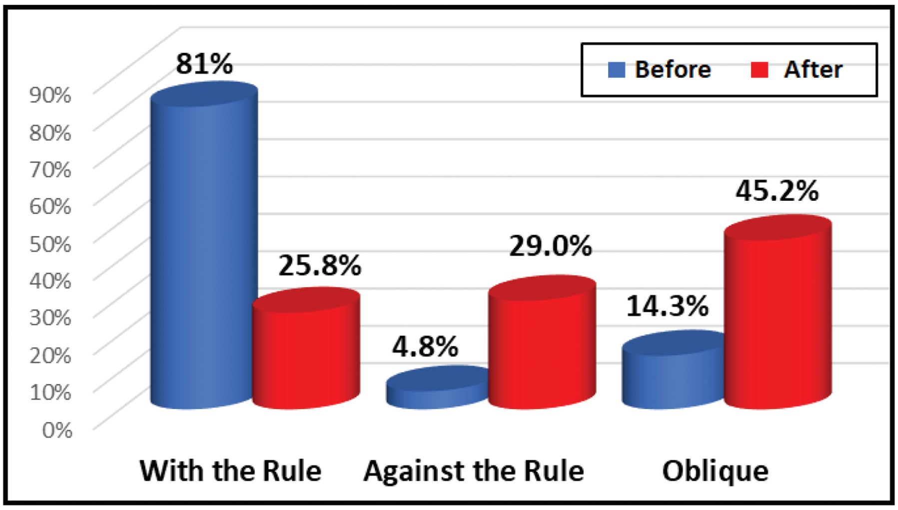
Ectasia after LASIK refers to a reduction in the biomechanical integrity of the cornea, resulting in unanticipated and progressive corneal steepening and thinning. It remains one of the most insidious and feared complications associated with visual morbidity [16]. Determining the risk factors and refining preoperative screening parameters could potentially eliminate or at least reduce the prevalence of this complication. Since the thickness, curvature, shape, and tensile strength of the cornea are modulated by

Table 8 Effect of treatment on corneal elevation in the ectasia group

Parameters	Before	After	P(a)
F/BFS			
Mean±SD	3.06±2.1	13.06±8.8	<0.001*
Median (IQR)	3 (3)	14 (12)	
B/BFS			
Mean±SD	7.32±5.9	38.71±17.8	<0.001*
Median (IQR)	7 (7)	40 (30)	
B-F			
Mean±SD	4.26±3.6	25.65±13.6	<0.001*
Median (IQR)	4 (3)	24 (20)	

B/BFS, back elevation at best fit sphere map; B-F, back to front elevation difference; F/BFS, front elevation at best fit sphere map; IQR, interquartile range. [a]Related-samples Wilcoxon signed rank test was used to compare the median on repeated measures. *Statistically significant.

Figure 2



Type of astigmatism before LASIK compared with after LASIK treatment among the ectasia group. LASIK, laser in situ keratomileusis.

LASIK surgery, this procedure changes the biomechanical properties of the cornea [17]. Within the cornea which becomes ectatic after LASIK, the postoperative chronic biomechanical failure process is represented as delamination and inter-fiber fracture [18].

The prevalence of post-LASIK ectasia in the current study was 0.22%. A similar prevalence of 0.2% was reported in the study of Rad *et al.* [19]. Other reported incidence rates range from 0.8 [20] to 0.03% [15]. Anecdotal evidence suggests that post-LASIK ectasia has declined after the introduction of the femtosecond laser [15].

In this study, no significant difference was reported between the ectasia and control groups regarding the demographic data. Several studies have considered young age to be a risk factor for ectasia [21,22], but others did not find such association [23]. In the study of Binder and Trattler [24] no ectasia developed after LASIK in patients of 21–29 years. Previous reports have elucidated nearly even sex distribution [16,25], but Randleman *et al.* [14] reported that post-LASIK ectasia occurred more frequently in males but in the overall study the sex differences remained undetermined.

Many studies have emphasized that correction of high preoperative refractive error is a significant risk factor for developing ectasia [16,23,26,27]. Preoperative myopia was significantly higher in ectasia cases of the current study than in normal patients. Corneal ectasia weakens the corneal tissue due to the amount of the stroma lost because of high myopia correction and some corneas may not withstand the ablation energy needed [21]. Furthermore, the high myopia possibly predisposes the cornea to a thinner RSB rather than independently raising the risk of ectasia [16]. This behavior could represent wound-healing 'regulators' in the cornea (such as keratocyte apoptosis [28]), which may play a role in the corneal remodeling process after the ablation. Derangement of the systems also may be a component in the pathogenesis of ectasia [27]. Among our studied sample, the presence of significant preoperative astigmatic refractive error (>1 D) was higher in the ectasia group than in the control group, which was also reported by Twa *et al.* [29]. The type of preoperative astigmatism was insignificant between the ectasia and control groups, in contrast to Twa *et al.* [29] who reported the magnitude of oblique astigmatism to be higher in the ectasia group. In this study, corneal astigmatism was significantly higher in the ectasia group. It was reported that greater corneal toricity was more frequently found among eyes with ectasia than in the comparison sample [29]. Lopes *et al.* [25] disagreed illustrating that corneal astigmatism was not statistically different between the stable group and the post-LASIK ectasia group.

The current study ectasia group had a worse preoperative CDVA than the comparison group, which was also reported by Twa *et al.* [29] and Padmanabhan *et al.* [30]. Unstable refractions and preoperative CDVA of less than 20/20 may be warning signs of undetectable ectatic disorders and may increase the risk of developing corneal ectasia after refractive surgery [31,32].

In the current study, the preoperative thickness at the thinnest corneal location was nonsignificantly less in the ectasia group (526.74±22.9 μm) than in the controls (532.92±27.5 μm), but the RSB thickness of the ectasia group (320.94±31.2 μm) was significantly less than that of the control group (343.08±33.2 μm). The high refractive errors of the ectatic groups resulted in deeper ablation and more weakening of the corneal tissue, which could explain the thinner RSB of the ectatic eyes. Some surgeons consider thin corneas with normal topography to be a risk factor for ectasia [11,14,16,33] but others disagree [34–36]. Furthermore, surgeons prefer not to perform LASIK in corneas with a central corneal thickness of less than 500 μm [9].

The preoperative K-max was significantly higher in our cases of ectasia than in normal cases. Miraftab *et al.* [23] reported that each D rise in K-max increased the chance of corneal ectasia by a factor of 1.5, and that K-max more than 47.0 D considerably increased the risk of ectasia compared with K-max of 45.0–47.0 D. Bilateral post-LASIK ectasia was reported in preoperative steep corneas with K-max more than 49 D [37]. In the current study, no significant difference was reported. In this study, differences regarding the elevation of back and front surfaces were not significant in contrast to Padmanabhan *et al.* [30]. Among the present study sample, the difference between the two groups in the elevation of the back surface was insignificant. Some researchers have reported that high posterior float was measured in ectatic eyes in comparison to eyes that did not develop ectasia [38,39].

The ectasia risk score system (ERSS) was designed to assign a scoring scale to preoperative and operative parameters and to design risk factors as a point system categorized into low, moderate, and high risk for surgeons to quantify the relative risk for developing ectasia after LASIK for each patient [40]. In the current study groups, the high risk of ectasia in ERSS was more frequent in the ectasia group (29%) than in the control group (7.7%). Even though not all patients with post-LASIK ectasia were recognized by this system, the ERSS has proven that it could evaluate the patients at risk of developing ectasia by the advantage of its cumulative weighted nature to evaluate multiple risk factors on a quantitative basis [41]. Bühren *et al.* [42] reported that according to the Randleman ectasia risk scores, 80.4% were classified correctly that eyes with four points or more should be excluded from undergoing LASIK.

Creating a thick flap reduces the amount of tissue available for excimer laser ablation, which increases the risk of developing ectasia. In addition, the relatively thick periphery of the meniscus-shaped flap may contribute to the development of ectasia. Stromal hydration found during the creation of a microkeratome flap could possibly account for the development of ectasia in some cases [15,43]. It was reported that thicker-than-expected flaps could be created by mechanical microkeratomes [44–46]. Miranda *et al.* [47] reported that the average flap thickness achieved with a 180 μm plate can be 131 ±28 μm, in agreement with Bohac *et al.* [15] who found that microkeratome flaps targeted at 110 μm can vary between 86 and 160 μm. Qazi *et al.* [48] suggested that surgeons could modify the flap depth and diameter to modulate the biomechanical stability of the cornea. In this study, there was no significant difference in corneal flap thickness between the two study groups.

In the current study, the residual bed thickness of the ectatic eyes was significantly less than that of normal eyes. Moreover, there was a significant difference between the two groups in the percentage of bed thickness to corneal thickness at the thinnest location. It has been observed that the RSB is one of the most important factors for post-LASIK ectasia [22,49,50]. Post-LASIK ectasia occurs when the remaining thin residual stroma cannot act as a barrier against mechanical stress. The lower safe limits of preoperative RSB thickness have been increasing gradually over the years from 200 to 300 μm to avoid this complication and to ensure preservation of an adequate posterior corneal residual bed [22]. In this study, the actual RSB and flap thickness were not measured directly as the RSB was calculated by subtraction of the assumed flap thickness and ablation depth from central corneal thickness, a potential source of error in the theoretical calculation. Factors contributing to errors in the calculation of the residual bed thickness include estimation of ablation depth, which is related to the optical zone and the profile of corneal ablation, and the ablation depth in LASIK could be greater than expected [51,52]. There can also be differences in the degree of laser ablation because the effective level of delivered energy is not always the same [53]. In addition, recent studies have reported that surgeons prefer to perform ablations with larger ablation zones to avoid postoperative glare, halos, and haze [22].

In this study, the rate of complications was significantly higher in the ectasia group than in the control group. These complications required LASIK retreatment in some cases and second flap creation in other cases. Other studies have suggested that LASIK enhancement may correlate with post-LASIK ectasia as this procedure removes the extra-stromal tissue [26,54,55]. It remains problematic, however, to determine whether numerous enhancements may participate in developing ectasia or whether they are performed more frequently in post-LASIK cases due to progressive myopic shift associated with ectasia [16].

Numerous studies have confirmed iatrogenic ectasia as a progressive corneal steepening and thinning, resulting in debilitation of visual acuity with irregular astigmatism [9,30,56]. The current study focused on comparing the changes before and after LASIK procedure in eyes that developed ectasia regarding astigmatism, corneal curvature, elevation, and thickness. In this study, refractions shifted dramatically during the postoperative period in ectatic eyes. The preoperative astigmatism in the ectasia group showed a significant increase after the development of ectasia. In addition, the astigmatism type before LASIK was also modified postoperatively. The percentage of oblique astigmatism and against the rule astigmatism increased significantly after ectasia. Similarly, Twa *et al.* [29] reported that after LASIK treatment, magnitudes of astigmatic components were significantly increased in the ectasia group. However, in their study, with the rule astigmatism and against the rule astigmatism increased postoperatively in the ectasia group. In the current study, there was a significant change in corneal astigmatism after LASIK when compared with the preoperative corneal astigmatism. We suggest that the development of oblique astigmatism after LASIK could be a warning sign for early ectasia development.

In this study, the K-max was significantly higher after developing ectasia than before surgery. In addition, the mean corneal curvature of the posterior surface increased significantly after keratectasia in comparison to before LASIK surgery, but not in the mean anterior corneal surface curvature. The corneal elevation of both the front and back surfaces increased significantly after ectasia development in comparison to the preoperative front and back elevation. In addition, the difference between back and front corneal elevations also showed a significant increase after post-LASIK ectasia.

Although this study included a high number of patients who underwent LASIK, the small number of ectasia cases and the retrospective nature of the study are the main limitations. Further studies with a large sample of ectasia cases and evaluation of corneal biomechanics could help in delineating the circumstances of post-LASIK ectasia.

Conclusion

The prevalence of post-LASIK ectasia in this study was 0.22%, meaning that it is a visually debilitating, albeit rare, complication of an elective refractive procedure. Risk factors for ectasia development included the degree of myopia, astigmatism, CDVA, K-max, ectasia risk scoring, residual stroma after LASIK, and retreatment. Although none of these risk factors are present in some cases of ectasia, clinicians should keep them in mind during the evaluation of patients willing to undergo LASIK for the correction of refractive errors.

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Conflicts of interest

There are no conflicts of interest.

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