ARTICLE

Analysis of cases and accuracy of 3 risk scoring systems in predicting ectasia after laser in situ keratomileusis

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Purpose: To identify risk factors for ectasia after laser in situ keratomileusis (LASIK) by comparing the accuracy of the Ectasia Risk Score System (ERSS), Screening Corneal Objective Risk of Ectasia (SCORE) Analyzer, and percentage of tissue altered (PTA) in predicting the occurrence of ectasia.

Setting: Multiple centers in 8 countries.

Design: Retrospective case series.

Methods: Previously unpublished post-LASIK ectasia cases were analyzed. Consecutive patients who had LASIK performed at least 5 years previously with no resultant ectasia were used as controls. Axial maps from preoperative Orbscan IIz topographies were analyzed in a masked fashion, and examination files tested with the SCORE Analyzer. The PTA values and ERSS scores were generated using available preoperative and perioperative data. Only eyes with subjectively identified normal preoperative topography were tested with the PTA. Threshold values for the SCORE, ERSS, and PTA were more than or equal to 0, 4, and 40, respectively.

Results: Ectasia occurred in 31 eyes (22 patients); 79 eyes (44 patients) were used as controls. In all eyes, the sensitivity and specificity for predicting ectasia, respectively, were 67.7% and 79.7% for the ERSS and 64.5% and 100% for the SCORE. In eyes with normal topography (ectasia group, 12 eyes; controls, 64 eyes), the PTA yielded sensitivity of 33.3% and specificity of 85.9%. The area under the receiver operating characteristic curve was highest for SCORE (0.911) followed by the ERSS (0.844) and PTA (0.557).

Conclusions: The SCORE was most predictive of ectasia, achieving the best specificity; the ERSS had the best sensitivity. Further studies are required to validate the PTA as a screening metric for ectasia.

J Cataract Refract Surg 2018; 44:979–992 © 2018 ASCRS and ESCRS

Ectasia after laser in situ keratomileusis (LASIK) refers to the reduction in the biomechanical integrity of the cornea, resulting in unanticipated and progressive corneal steepening and thinning associated with increasing myopic astigmatism.[1] Although rare, with a reported incidence between 0.04% and 0.6%,[2] it remains one of the most devastating complications after LASIK.

Various risk factors for the development of ectasia have been identified, of which abnormal preoperative topography has been described to be one of the most important.[3,4] Improved topography and risk assessment systems have been developed with the aim of detecting subclinical or forme fruste keratoconus in its earliest stages. Saad and Gatinel[5] found that the addition of elevation and tomography to Placido data in the evaluation of suspicious corneas gives good sensitivity and specificity in detecting early forms of keratoconus. The indices generated from cornea thickness and curvature measurements over the entire

Submitted: September 17, 2017 | Final revision submitted: March 27, 2018 | Accepted: May 15, 2018

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Supported in part by an unrestricted grant to the USC Roski Eye Institute, Los Angeles, California, from Research to Prevent Blindness, New York, New York, USA.

Hla Myint Htoon, PhD, Singapore Eye Research Institute, Singapore, provided advice on statistical analysis. Ben D'Heer, MD, Ophthalmology Laser Clinic, Deurne, Belgium; Louis Racine, MD, and Julie Vadboncoeur MD, Departement d'Ophthalmologie, Université de Montréal, Canada; and Natasha Pahuja, MD, Narayana Nethralaya Hospital, Bangalore, India, assisted in data collection.

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0886-3350/$ - see frontmatter
https://doi.org/10.1016/j.jcrs.2018.05.013

cornea centered on the thinnest point and calculations of percentage changes in the thickness and anterior and posterior curvature variations are able to identify very mild or early forms of keratoconus undetected by Placido-based topography alone.[5] This concept was used to create an artificial intelligence system that has since been incorporated into the Screening Corneal Objective Risk of Ectasia (SCORE) Analyzer, a software linked to the Orbscan IIz topography system (Bausch & Lomb Technolas) designed to detect forme fruste keratoconus. The system generates a SCORE number that quantitatively and objectively categorizes the topography as negative or positive for topographic risk of ectasia. The SCORE Analyzer algorithm has been validated in white eyes and Asian eyes.[6,7]

Randleman et al.[4] developed the Ectasia Risk Score System (ERSS) in 2008. This quantitative method of describing the risk for ectasia is based on 5 criteria in a weighted fashion in order of importance as follows: preoperative Placido-based topography pattern, residual stromal bed thickness (RSBT), patient age at the time of surgery, preoperative corneal thickness, and treated manifest refraction spherical equivalent (MRSE). This system aims to recognize a variety of factors contributing to a continuum of the risk for ectasia. A cumulative scoring scale categorizes the risk for ectasia after LASIK into low, moderate, and high. This system has been evaluated and validated in several studies.[8,9] The topography scoring in the system is defined solely by Placido patterns and indices and remains subjective.

More recently, the percent tissue altered (PTA) was introduced as a new risk factor for ectasia. The PTA represents the percentage of anterior tissue modified during LASIK. Santhiago et al.[10] described it to be an individualized measure of biomechanical alteration that considers the relationship between the corneal thickness, tissue altered through excimer laser ablation and flap creation, and ultimate RSBT, and recommended it as a screening metric for refractive surgery candidates. In their subsequent study of eyes with suspicious preoperative topography,[11] the PTA was found to have a higher discriminative capability than RSBT for post-LASIK ectasia. At present, there are no published case series independently validating the PTA in eyes with post-LASIK ectasia.

Our study aimed to validate the SCORE Analyzer, ERSS, and PTA by using unpublished cases of post-LASIK ectasia and testing each system's accuracy in predicting the occurrence of ectasia. By comparing the sensitivity and specificity of each, the authors aimed to identify risk factors for post-LASIK ectasia and isolate important characteristics contributing to the disease. Finally, we wanted to suggest improvements (if any) to the systems.

PATIENTS AND METHODS

This study involved the retrospective review of patient case records and was performed in accordance with the ethical principles that have their origin in the tenets of the Declaration of Helsinki. Coauthors were invited to participate in the study through electronic and personal communication. Ectasia cases included in the study were patients referred to or had LASIK performed by the individual coauthors. After confirmation of the ectasia diagnosis, case records of the identified patients were retrieved and evaluated. The control group comprised consecutive patients who had uneventful LASIK with no resultant ectasia and with a minimum of 5 years of follow-up at the Rothschild Foundation, Paris, France. These patients were deemed suitable for LASIK and had LASIK performed based on the empirical judgment of the attending refractive surgeon and without testing with the ERSS, SCORE Analyzer, or PTA at the time of preoperative screening for LASIK suitability.

All data collected from the ectasia and control groups were collated and analyzed at the Rothschild Foundation and Singapore National Eye Centre, Singapore.

Post-LASIK ectasia was defined as progressive inferior steepening of the cornea after LASIK confirmed on corneal topography, with increasing myopia and astigmatism and loss of uncorrected distance visual acuity and often corrected distance visual acuity.[12] All patients included in the analysis had uneventful LASIK and good vision before developing ectasia.

Only cases with the relevant and necessary preoperative, perioperative, and postoperative data available for analysis were recruited into the study. This included preoperative Orbscan IIz topographies with raw data examination (.exm) files sufficiently captured for analysis with the SCORE Analyzer, parameters for computation of the ERSS and PTA, and postoperative clinical data documenting ectasia. Where flap thickness was not directly measured, it was estimated based on device characteristics.

All topographies were obtained by experienced operators. Eyes with a history of corneal injury, corneal scarring, ocular surgery, and ocular surface or other ophthalmic disease that could potentially affect the outcomes of the study were excluded, as were patients with possible corneal warpage from contact lens wear. All patients enrolled were without contact lens use for at least 1 week (soft contact lenses) or 2 to 3 weeks (rigid gas-permeable contact lenses) at the time the topographies were performed.

Parameters computed included the patients' demographics (age at time of LASIK, race/ethnicity, and sex), onset of ectasia (in years) after LASIK, flap-cutting device (microkeratome or femtosecond laser), treated MRSE, minimum cornea thickness, intended flap thickness, ablation depth, and calculated RSBT.

Topography Analysis

Preoperative topographies were compiled and patient identifiers removed. Color anterior curvature (axial) maps with a 0.50 diopter (D) scale were masked with regard to the occurrence of ectasia and sent electronically to one of the coauthors (J.B.R.), the principal author responsible for the formulation of the ERSS, for analysis and categorization. The topographies were analyzed and subjectively scored 0, 1, 3, or 4 accordingly as normal, asymmetric bow-tie, inferior steepening or skewed radial axis, or abnormal topography as described and defined in Randleman et al.'s original study.[4]

Screening Corneal Objective Risk for Ectasia Analysis and Number Generation

The examination files of the individual preoperative topographies retrieved were tested with the SCORE Analyzer to generate the SCORE number. As defined in Saad and Gatinel's original study,[5] zero or a positive (non-negative) number (SCORE ≥ 0) would indicate positive for topographic risk of ectasia and a negative number would indicate no topographic risk. The theory behind the derivation and calculation of the SCORE number, including detailed descriptions of the radar map and pachymetry data graphs of the SCORE Analyzer, have been published.[5,6]

Corneal Thickness Measurements

The minimum corneal thickness was recorded as the minimum thickness documented on the topographer, flap thickness as the

intended flap thickness with the microkeratome head or femtosecond laser, and ablation depth as documented on the printout of the excimer laser. The predicted RSBT was calculated by subtracting the intended/assumed flap thickness and ablation depth from the cornea thickness as follows:

$$RSBT = CT - FT - AD$$

where FT is the intended flap thickness, CT is the corneal thickness, and AD is the ablation depth.

Ectasia Risk Score System Calculation

The ERSS criteria were applied to this study, and the eyes were scored based on the scale shown in Table 1. Based on the recommendations of the ERSS,[4] a cumulative risk score of 4 or more was categorized as being at high risk for developing post-LASIK ectasia, and 3 or more as being at medium risk. In this study, at risk for ectasia was defined as having a risk score of 4 or more, in keeping with the methodology applied in the initial papers.[4,8] Although these papers recommended exclusion from excimer laser corneal refractive surgery bilaterally if patients have a suspicious topographic pattern in either eye, in this study the eyes were evaluated individually.

Calculation of Percent Tissue Altered and Definition of Abnormal Values

As detailed in Santhiago et al.'s original study,[10] the PTA was calculated based on the formula

$$PTA = \frac{(FT + AD)}{CCT}$$

where FT is the flap thickness, AD is the ablation depth, and CCT is the central corneal thickness preoperatively. For corneas with normal preoperative topography on Placido analysis, an abnormal PTA indicating at risk for ectasia was defined as a PTA of 40 or more.[10] Although the initial study was performed using ultrasound (US) pachymetry for corneal thickness evaluations and measured flap thickness and required bilateral topography assessment, this study used corneal thickness measured by the topographer, estimated flap thickness based on manufacturer markings, and assessed PTA in individual eyes.

Definition of Normal Topography

In the study defining PTA,[10] *normal topography* was defined as "regular and symmetric patterns (including round, oval, or symmetric bowtie patterns) or mildly asymmetric (steepening $\leq$0.5 D and without skewed radial axis) based on Placido-disc analysis." The present study included all cases with topographies scored 0 and 1 that fit this definition of normal topography for PTA analysis and applied this definition of normal topography. Topographies scored 3 and 4 were thus defined as having abnormal topography.

In a subsequent study of eyes with suspicious and abnormal topography,[11] the authors did not define a cutoff point for the cases, although they suggested that a lower PTA value was in keeping with the finding that less tissue alteration was necessary to induce ectasia in eyes with biomechanically less stable corneas. Because of the paucity of data on this, all eyes with abnormal topography by the study definitions were excluded from PTA analysis in the present study.

Subgroup Analysis of Eyes with Normal Topography

To directly compare the efficacy of abnormal PTA with the ERSS and SCORE Analyzer in predicting ectasia in this series of cases, an analysis of the sensitivity and specificity of ERSS and SCORE Analyzer was performed in a subgroup of eyes with normal topography. Whether a single system or combination of systems was more accurate in predicting ectasia risk this subgroup was also determined.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 19.0, IBM Corp.) with significance set at a P value less than 0.05. Group data were compared using the Fisher exact test, Mann-Whitney U test, Wilcoxon signed-rank test, or McNemar test. After the sensitivity and specificity were determined, the performance of the 3 systems was compared by plotting the receiver operating characteristic (ROC) curves.

RESULTS

The study population comprised 31 eyes of 22 patients in the ectasia group and 79 eyes of 44 patients in the control group. Thirteen patients had unilateral ectasia, and 9 patients had bilateral ectasia.

Demographics

In the ectasia group, 9 patients (40.9%) were men. Fourteen patients (63.6%) were white, 3 (13.6%) were Arab, 2 (9.0%) were Chinese, 2 (9.0%) were Indian, and 1 (4.5%) was African-American. The mean age at LASIK was 29.6 years $\pm$ 6.1 (SD) (range 18 to 41 years). The mean time to ectasia was 3.5 years, with the earliest occurring 6 months after surgery and the latest occurring 7 years after the procedure. Twenty ectatic eyes (64.5%) had LASIK with a microkeratome and the rest, with a femtosecond laser.

In the control group, 16 patients (36.4%) were men. The mean age at LASIK was 29.0 $\pm$ 4.9 years (range 21 to 42 years). Thirty-seven patients (84.1%) were white, 6 (13.7%) were North African, and 1 (2.2%) was Chinese. All eyes had LASIK with a femtosecond laser.

Table 1. Ectasia Risk Score System.

	Points				
Parameter	4	3	2	1	0
Topography	Abnormal	Inferior steepening/ skewed radial axis	—	Asymmetric bowtie	Normal/symmetrical bowtie
RSBT (μm)	<240	240 to 259	260 to 279	280 to 299	≥300
Age (y)	—	18 to 21	22 to 25	26 to 29	≥30
CT (μm)	<450	451 to 480	481 to 510	—	≥510
MRSE (D)	>−14.0	>−12.0 to −14.0	>−10.0 to −12.0	>−8.0 to −10.0	≥−8.0

CT = minimum cornea thickness; MRSE = manifest refraction spherical equivalent; RSBT = residual stromal bed thickness

Table 2. Between-group comparison of refraction and corneal thickness measurements and test values.

Parameter	Ectasia Group (n = 31)		Control Group (n = 79)		*P* Value*
	Mean ± SD	Range	Mean ± SD	Range	
MRSE (D)	−4.93 ± 1.82	−2.75, −9.50	−4.57 ± 2.28	−1.38, −12.13	.218
CT (μm)	524.1 ± 34.4	459, 603	560.9 ± 29.0	505, 637	<.001
FT (μm)	123.8 ± 24.9	80, 180	121.5 ± 4.6	120, 130	.047
AD (μm)	80.0 ± 30.1	42, 153	70.7 ± 26.0	27, 143	.228
RSBT (μm)	320.4 ± 43.8	236, 405	368.7 ± 39.2	301, 453	<.001
SCORE	0.7 ± 1.7	−2.8, 5.0	−2.3 ± 0.9	−4.5, −0.1	<.001
PTA	38.9 ± 7.0	28.0, 52.4	34.4 ± 4.8	26.0, 45.2	<.001
ERSS	4.7 ± 2.1	1, 12	2.0 ± 1.6	0, 6	<.001

AD = ablation depth; CT = minimum cornea thickness; ERSS = Ectasia Risk Score System; FT = intended flap thickness; MRSE = manifest refraction spherical equivalent; PTA = percent tissue altered; RSBT = predicted residual stromal bed thickness; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer

*Independent-samples Mann-Whitney *U* test

Refraction and Cornea Thickness Measurements

Table 2 shows the refraction, corneal measurements and test values in eyes with ectasia and control eyes. The mean corneal thickness, RSBT, SCORE value, ERSS score, and PTA value were statistically significantly different between the ectasia group and control group.

Topography Analysis

Of the 31 eyes with ectasia, 61.3% (19 eyes) were subjectively classified as having abnormal Placido topography. One eye (3.2%) was scored 0, 11 eyes (35.5%) were scored 1, 12 eyes (38.7%) were scored 3, and 7 eyes (22.6%) scored 4.

In the control group, 81.0% (64 eyes) were subjectively classified as having normal Placido topography. Twenty-six eyes (32.9%) were scored 0, 38 eyes (48.1%) were scored 1, 13 eyes (16.5%) were scored 3, and 2 eyes (2.5%) were scored 4.

In the 31 eyes with ectasia, the SCORE number was zero or positive (SCORE ≥0) in 20 eyes, indicating positive for topographic risk of ectasia and sensitivity of predicting ectasia occurrence in 64.5% of the 31 eyes.

In the control group, the SCORE was less than 0 in all 79 eyes, indicating no topographic risk of ectasia and giving a specificity of predicting ectasia occurrence in 100% of cases. The ROC curve plotted showed the area under the ROC curve at 0.964 (Figure 1).

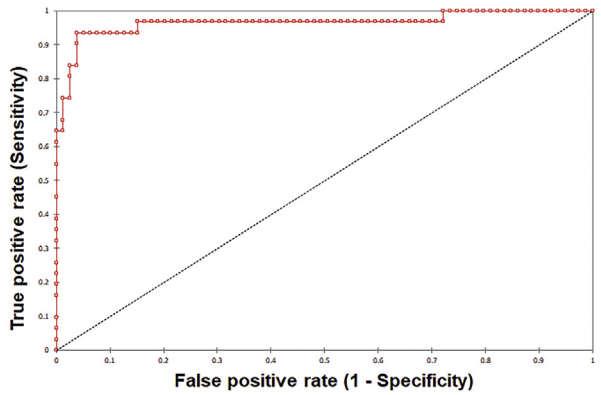
Ectasia Risk Score System

According to the ERSS, 21 of the 31 ectatic eyes were classified as at high risk for ectasia (ERSS ≥4), giving a sensitivity of 67.7%. Twenty-eight ectatic eyes (90.3%) were classified as having a moderate risk (ERSS ≥3).

In the controls, 63 out of 79 eyes were classified as having a low to medium risk (ERSS ≤3), giving a specificity of 79.7%. Fourteen eyes (17.7%) had an ERSS score of 3, while 16 eyes (20.3%) had a score of 4 or more. The area under the ROC curve was 0.853 (Figure 2).

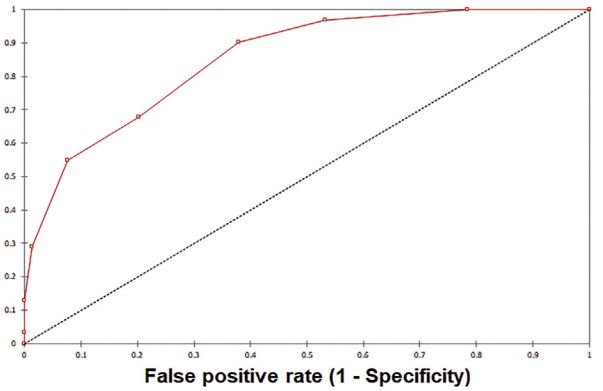
Percent Tissue Altered

The sensitivity and specificity of the PTA could only be determined for eyes with normal topography because the cutoff point for the PTA has been discussed only for



	AUC	Standard Error	95% Confidence Interval
SCORE Analyzer	0.964	0.028	0.910 to 1.000

Figure 1. The ROC curve for SCORE more than or equal to 0 (all eyes) showing the area under ROC (AUC = area under the curve; ROC = receiver operating characteristic; SCORE = Screening Corneal Objective Risk of Ectasia).



	AUC	Standard Error	95% Confidence Interval
ERSS	0.853	0.042	0.771 TO 0.936

Figure 2. The ROC curve for ERSS more than or equal to 4 (all eyes) showing the area under the ROC (AUC = area under the curve; ERSS = Ectasia Risk Score System; ROC = receiver operating characteristic).

eyes with topographically normal corneas based on Placido indices defined by the ERSS topographic criteria.

Table 2 shows the SCORE, PTA, and ERSS values for all eyes. Table 3 shows the key parameters used in the computation of the PTA and ERSS scores for each ectatic eye.

Subgroup Analysis of Eyes with Normal Topography for Percent Tissue Altered

Twelve eyes with ectasia and 64 eyes in the control group were subjectively classified as having normal topography by the study's definitions. In the ectasia group, 8 eyes of 4 patients were subjectively classified as having bilateral normal topography. In the eyes with ectasia, the mean age at LASIK was 28.4 ± 6.4 years. Four eyes had PTA greater than 40, giving a sensitivity of 33.3%. The mean PTA was 37.4 ± 7.3 (range 28.6 to 52.4). In the control group, the mean age at LASIK was 29.7 ± 5.0 years. Fifty-five eyes had PTA less than 40, giving a specificity of 85.9%. The mean PTA was 35.0 ± 4.7 (range 26.1 to 45.2).

Figures 3 to 5 show the area under the ROC curve for a PTA more than or equal to 40, an ERSS more than or equal to 4, and a SCORE more than or equal to 0, respectively.

For the 5 patients (8 eyes) with ectasia that had a false-negative PTA, the mean age at LASIK was 28.6 ± 7.5 years.

Efficacy of Combined Systems in Eyes with Normal Topography

Tables 4 and 5 show the sensitivities of the systems individually and when combined. Sensitivity was highest when all 3 systems were used in combination at 83.3%.

Tables 6 and 7 show the specificity of the systems individually and when combined. Specificity was highest when a SCORE more than or equal to 0 was applied on its own (100%) and lowest when all 3 systems were used in combination or when ERSS more than or equal to 4 was combined with a PTA more than or equal to 40 (82.8%).

Significance of Intended Versus Measured Flap Thickness in Percent Tissue Altered Evaluation

Table 8 shows the results of a comparison of the flap thickness necessary to generate a PTA of 40 with the intended flap thickness logged in the study in all 8 false-negative cases to determine whether the sensitivity of the PTA was affected by the use of intended flap thickness. The mean difference in flap thickness was 36.6 μm (range 19 to 62 μm). An overcut of 30 μm or more would have been required in 6 of these eyes (75.0%) for a PTA to be 40 or more. Five of these 6 eyes (83.3%) had flaps created with the femtosecond laser in which gross overcuts are possible but less likely. One flap would have had to be overcut by 62 μm to fulfill the "40 threshold" value.

Case Examples from Table 3

Case 1 (serial numbers 14 and 15: positive SCORE; negative ERSS and PTA) A 40-year-old white man had uneventful femtosecond LASIK and developed ectasia in both eyes 3 years later. In the right eye and left eye, respectively, minimum corneal thickness was 495 μm and 496 μm, the MRSE was −3.65 and −3.60 D, and the predicted RSBT was 330 μm and 331 μm. The intended flap thickness was 110 μm and the ablation depth was 55 μm bilaterally. Both eyes were categorized as being at moderate risk on the ERSS because of an asymmetric bowtie on the axial map (1 point) and a thin cornea (2 points). The PTA was falsely negative (33.3) in both eyes. Figure 6 shows the preoperative and postoperative topographies and SCORE Analyzer assessment of both eyes. The SCORE value was positive for topographic risk of ectasia at 0.3 and 0.1 for the right eye and left eye, respectively, by virtue of a thin cornea, mild increase in the inferior–superior value, and increased pachymetry thinning rate.

Case 2 (serial number 30: all 3 systems positive) A 34-year-old white woman who had bilateral uneventful femtosecond LASIK developed unilateral ectasia in the right eye 3.5 years later. The MRSE was −5.63 D with an ablation depth of 105 μm and an intended flap thickness of 110 μm. The eye was categorized as high risk by the ERSS (5 points) by virtue of the thin cornea (491 μm) (2 points), low predicted RSBT (276 μm) (2 points), and asymmetric bowtie on the axial map (1 point). The PTA classified the eye as at risk, with a value of 43.8. Figure 7 shows the preoperative and postoperative topographies and SCORE Analyzer assessment. The SCORE value was positive for a topographic risk for ectasia (1.2) by virtue of a thin cornea, high irregularity at 3.0 mm, and inferior decentration of the thinnest point.

Case 3 (control eye with negative SCORE and positive ERSS) Figure 8 shows the preoperative and postoperative topographies of a 25-year-old white man who had bilateral uneventful femtosecond LASIK performed 5 years previously with no resultant ectasia. The MRSE, minimum corneal thickness, flap thickness, ablation depth, and predicted RSBT were −2.88 D, 571 μm, 120 μm, 49 μm, and 402 μm, respectively. The SCORE value was negative at −1.8; however, the ERSS topography grading was subjectively scored a 3 (skewed radial axis) on axial map analysis. This topography scoring combined with young patient age (2 points) gave a combined score of 5 on the ERSS, thus classifying it as at high risk for ectasia. The PTA could not be analyzed in this case as the topography was subjectively classified as abnormal.

Case 4 (serial number 26: all 3 systems negative) A 26-year-old Indian woman developed bilateral ectasia 4 years after uneventful femtosecond LASIK. Figure 9 shows the preoperative and postoperative topographies and SCORE Analyzer assessment of the left eye. The MRSE was −3.75 D, the preoperative minimum cornea thickness was 519 μm, the intended flap thickness was 120 μm, the ablation depth was 51 μm, and the predicted RSBT was 348 μm. The ERSS categorized the eye at low risk for ectasia (1 point for asymmetric bowtie on topography and 1 point for young patient age). The PTA was falsely negative at 32.9. The SCORE Analyzer also categorized the eye as having no topographic risk of ectasia, with a value of −0.2. No other risk factors for ectasia

Table 3. Summary of key parameters in eyes with ectasia.

S/N	Age (Y)	Time to Ectasia (Y)	MK/FS	MRSE (D)	CT (μm)	FT (μm)
1	25	4.0	MK	−6.375	484	120
2	30	2.0	MK	−8.25	549	120
3	25	5.5	MK	−9.50	552	120
4	38	2.0	MK	−3.50	561	140
5	28	1.0	FS	−3.50	561	110
6	31	7.0	MK	−5.00	512	160
7	22	5.0	MK	−4.50	491	110
8	18	1.5	MK	−5.6205	534	115
9	18	1.5	MK	−6.00	525	115
10	32	2.5	MK	−2.875	546	110
11	32	2.5	MK	−3.375	562	110
12	41	0.5	MK	−2.75	556	120
13	41	0.5	MK	−4.875	603	120
14	40	3.0	FS	−3.65	495	110
15	40	3.0	FS	−3.60	496	110
16	27	7.0	FS	−8.395	519	100
17	35	6.0	FS	−8.625	486	80
18	35	6.0	FS	−6.50	493	90
19	33	1.5	MK	−3.06	496	147
20	33	1.5	MK	−3.50	499	150
21	33	2.0	MK	−5.375	521	160
22	23	3.5	MK	−5.00	580	160
23	23	3.5	MK	−5.625	571	180
24	23	4.0	MK	−5.25	519	110
25	26	4.0	FS	−3.00	524	120
26	26	4.0	FS	−3.75	519	120
27	33	3.0	MK	−4.00	534	180
28	23	5.0	FS	−3.63	471	100
29	23	5.0	FS	−3.625	459	100
30	34	3.5	FS	−5.625	491	110
31	32	6.0	MK	−4.50	538	140

AD = ablation depth; CT = minimum corneal thickness; ERSS = Ectasia Risk Score System; FT = intended flap thickness; MK/FS = microkeratome/femtosecond laser used for flap creation; MRSE = manifest refraction spherical equivalent; PTA = percent tissue altered; RSBT = predicted residual stromal bed thickness; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer; S/N = serial number

could be determined for this patient. She denied excessive or compulsive eye rubbing, was negative for a history of atopy or signs of coexisting allergic eye disease, and had no family history of keratoconus or ectatic eye disease. There was no documented pregnancy from the time of LASIK to the development of ectasia.

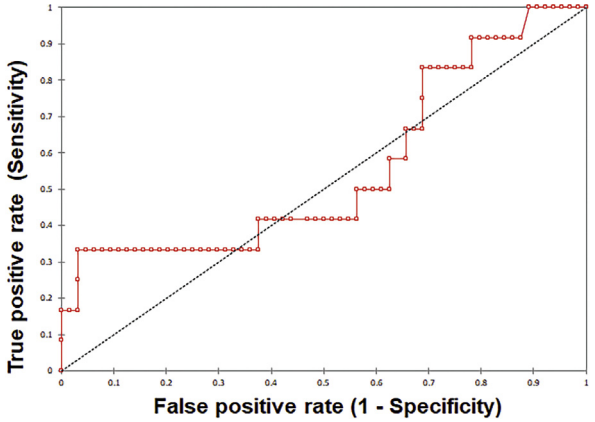
DISCUSSION

Risk factors for post-LASIK ectasia have been extensively discussed and evaluated. In earlier publications, traditional cutoff values, such as a preoperative corneal thickness of 500 μm or less, a thin RSBT of 250 μm, high myopia of more than −8.0 D, and patient age younger than 25 years, were all considered possible risk factors for the development of ectasia.[3,12–14] However, it was subsequently found that when these individual factors were considered in isolation to define the risk for ectasia development, false positives were generated.[15] In our series of eyes with ectasia, the mean of RSBT, MRSE, minimum cornea thickness, and patient age values were all higher than the traditionally defined cutoff values. Thus, high myopia, a thin cornea, and a low RSBT were not risk factors for ectasia in our ectasia population.

The ERSS was devised to assign a risk scale to preoperative and operative parameters and amalgamated designated risk factors as a point system for refractive surgeons to quantify the relative risk for developing ectasia after LASIK for each individual patient. Abnormal preoperative topography defined by Placido indices, a low RSBT, young patient age, thin preoperative corneal thickness, and higher attempted refractive corrections were the designated risk factors.[4] The ERSS has been retrospectively tested in several studies. Randleman et al.[8] validated their own work with a separate group of 50 previously unpublished ectasia cases and achieved sensitivity of 92% and specificity of 94%, based on an ERSS score of more

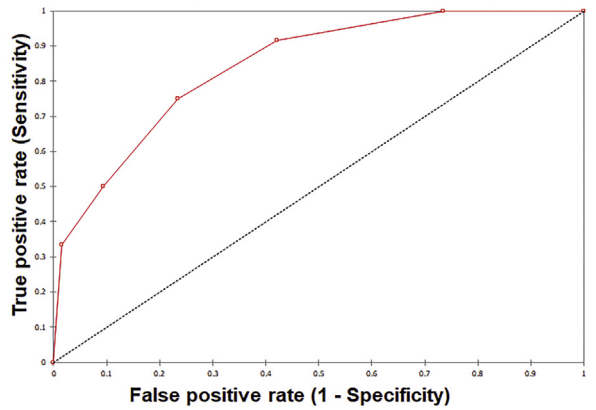
Table 3. (Cont.)

AD (μm)	RSBT (μm)	Topography Score (ERSS)	SCORE Analyzer	PTA	ERSS
128	236	4	0.1	51.2	12
153	276	4	0.2	49.7	7
110	322	3	−0.6	41.7	6
47	374	3	1.1	33.3	3
47	404	3	1.6	28.0	4
68	284	4	0.2	44.5	5
67	314	1	−0.7	36.0	5
103	316	3	−0.4	40.8	6
111	299	3	−0.5	43.0	7
46	390	1	0.0	28.6	1
54	398	3	0.2	29.2	3
54	382	4	1.7	31.3	4
78	405	3	2.4	32.8	3
55	330	1	0.3	33.3	3
55	331	1	0.1	33.3	3
125	294	1	−0.8	43.3	4
114	292	3	3.1	40.0	7
90	313	4	5.0	36.5	6
68	281	3	2.1	43.3	6
66	283	3	3.6	43.3	6
65	296	4	3.7	43.2	5
111	309	1	−1.4	46.7	3
119	272	1	−2.8	52.4	5
66	343	3	0.3	33.9	5
42	362	1	−0.4	30.9	2
51	348	1	−0.2	32.9	2
74	280	4	3.1	47.6	5
55	316	0	−0.7	32.9	5
56	303	1	−0.5	34.0	6
105	276	1	1.2	43.8	5
96	302	3	1.6	43.9	3



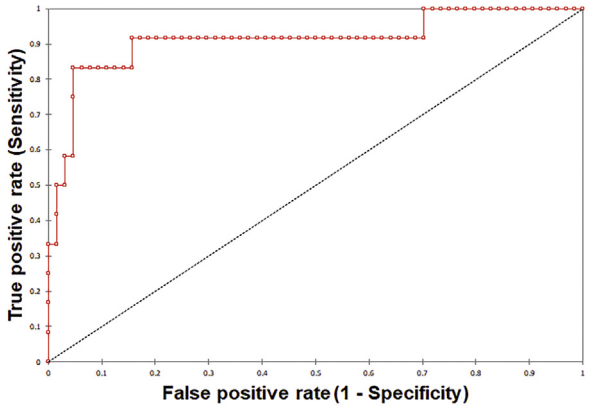
	AUC	Standard Error	95% Confidence Interval
PTA	0.557	0.115	0.331 to 0.782

Figure 3. The ROC curve for PTA more than or equal to 40 (eyes with normal topography) showing the area under the ROC (AUC = area under the curve; PTA = percentage of tissue altered; ROC = receiver operating characteristic).



	AUC	Standard Error	95% Confidence Interval
ERSS	0.844	0.062	0.723 to 0.966

Figure 4. The ROC curve for ERSS more than or equal to 4 (eyes with normal topography) showing the area under the ROC (AUC = area under the curve; ERSS = Ectasia Risk Score System; ROC = receiver operating characteristic).



	AUC	Standard Error	95% Confidence Interval
SCORE Analyzer	0.911	0.066	0.781 to 1.000

Figure 5. The ROC curve for SCORE more than or equal to 0 (eyes with normal topography) showing the area under the ROC (AUC = area under the curve; ROC = receiver operating characteristic; SCORE = Screening Corneal Objective Risk of Ectasia).

than or equal to 4 (high risk for ectasia). In their series, 46% of cases had abnormal preoperative topography. In Chan et al.'s study[16] in which topography was abnormal in 69% of cases, sensitivity of the ERSS in classifying cases at high risk was only 56%. Binder and Trattler[17] concluded that in eyes with normal preoperative topography, the ERSS might not accurately predict whether patients are at increased risk for developing ectasia. They reported that the ERSS overestimated the ectasia risk in eyes with normal preoperative topography when patients were followed for at least 1 year postoperatively. In Santhiago et al.'s study[10] comparing the prevalence and odds ratios (ORs) of the PTA and ERSS in eyes with normal preoperative topography that developed ectasia postoperatively, the sensitivity of an ERSS score more than or equal to 4 was only 20%, with a specificity of 97%. In our study, in which topography was subjectively classified as abnormal in 61.3% of ectatic eyes and 19.0% of control eyes, an ERSS score of more than or equal to 4 achieved sensitivity of 67.7% and specificity of 79.7%. If we were to define at risk of ectasia as an ERSS score of more than or equal to 3 (medium risk), the sensitivity would be higher at 90.3% but the specificity would be lower at 62.0%. The variable outcomes in these studies are partly linked to differences in study design, subjectivity in topography interpretation, and variability in length of follow-up, but they also suggest that modifications to the scoring system of the ERSS should be considered.

Abnormal preoperative topography remains the greatest independent risk factor for post-LASIK ectasia,[3,4,14] although corneas with normal topographies preoperatively have also been reported to develop ectasia after LASIK.[18] When the ERSS was devised, topography was scored based on Placido indices and patterns only. Although Placido-based topography has been found to be a sensitive method of diagnosing keratoconus,[19,20] Placido analysis and axial map interpretation rely on the subjective interpretation of the clinician and can be variable.[21] Artificial intelligence systems combining Placido imaging with other data to detect subclinical keratoconus or forme fruste keratoconus have been devised. The sensitivity and specificity of detection have been improved by tomography or pachymetry mapping to determine anterior and posterior cornea elevation with corneal wavefront data and pachymetric variations across the cornea to discriminate between eyes with forme fruste keratoconus from normal eyes.[5,22–25]

The Orbscan IIz system uses slit-scanning technology combined with a Placido disk system for corneal topography analysis. On its own, it does not give an objective assessment of ectasia risk but instead relies on the subjective interpretation of the color maps and indices by the clinician. The SCORE Analyzer was thus devised to provide objectivity to the topographer's interpretation. By combining Placido topography, elevation, and pachymetric indices generated by the topographer to assess the cornea, the SCORE Analyzer, through linear discriminant analysis, builds a model to discriminate between healthy corneas and corneas with forme fruste keratoconus.[5,6] Of particular importance is the tomographic data of corneal thickness variations throughout the entire cornea. The SCORE Analyzer value is a result of discriminant function analysis of 12 indices and is expressed as a single number that, by its negativity or positivity, aims to objectively indicate the risk for forme fruste keratoconus or to the refractive surgeon, the topographic risk for ectasia. The absolute numerical value of the SCORE value (how positive or negative) provides the clinician with objective information on the magnitude of the risk.[5,6]

All eyes in our study had a preoperative topography with the Orbscan IIz system, and we used the axial maps

Table 4. Summary of sensitivity of the 3 scoring systems.

	All Eyes			Eyes with Normal Topography		
	Number (%)			Number (%)		
System	Eyes with Ectasia (n = 31)	Mean ± SD	Range	Eyes with Ectasia (n = 12)	Mean ± SD	Range
SCORE ≥0	20 (64.5)	0.7 ± 1.7	−2.8, 5.0	4 (33.3)	−0.5 ± 0.9	−2.8, 1.2
PTA ≥40	NA	NA	NA	4 (33.3)	37.4 ± 7.3	28.6, 52.4
ERSS ≥4	21 (67.7)	4.7 ± 2.1	1, 12	6 (50.0)	3.7 ± 1.6	1.0, 6.0

ERSS = Ectasia Risk Score System; NA = not applicable; PTA = percent tissue altered; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer

Table 5. Sensitivity of the systems used in combination in eyes with normal topography (n = 12).

Systems	Sensitivity (%)	Eyes (n)
ERSS + SCORE + PTA	83.3	10
ERSS + SCORE	75.0	9
SCORE + PTA	58.3	7
ERSS + PTA	58.3	7

ERSS = Ectasia Risk Score System; PTA = percent tissue altered; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer

generated by the topographer to compute the topographic risk assessment based on the scoring outlined in the ERSS. The Placido analysis of all 31 eyes with ectasia was deemed normal by the attending refractive surgeons, who proceeded to perform LASIK on the patients. In contrast, the axial map interpretation by a coauthor (J.B.R.) showed abnormal topography in 61.3% of eyes (19 of 31 eyes). Before receiving this topographic scoring, we sought the interpretation of another experienced coauthor (D.G.), who was also tasked to score the topographies in a masked fashion. He found abnormal topography in 35.5% of the eyes (11 of 31) with ectasia. This variability in axial map interpretation between 2 very experienced refractive surgeons indicates that Placido interpretation is subjective and that a more objective means of topography interpretation would be advisable for risk assessment in refractive surgery.

The low specificity of the ERSS was attributable to 19.0% of eyes in the control group being subjectively classified as having abnormal topography on Placido map interpretation. The SCORE Analyzer objectively scored all these eyes as negative for a topographic–tomographic risk for ectasia. A specificity of 100% for a SCORE value of more than or equal to 0 and a highest area under the ROC of 0.964 indicate that in our series of cases, an objective topographic–tomographic system was more accurate at predicting the risk for ectasia than a system based solely on pachymetric considerations (PTA) and an amalgamated scoring system based on subjective Placido analysis, refraction, patient age, and thickness measurements (ERSS).

The current cutoff point of the SCORE Analyzer for forme fruste keratoconus and keratoconus detection was originally determined by plotting ROC curves and adjusted to correspond to a value of zero. In our study, if the SCORE value threshold was adjusted to more than −0.85, sensitivity would have been 93.5% and specificity would have been 96.2% (Table 9). In our series of cases, a SCORE value greater than −0.85 would therefore be a more robust indicator of the risk for ectasia.

The PTA as a risk factor hinges on a perceived integrated relationship between the preoperative corneal thickness, ablation depth, and flap thickness in determining the amount of biomechanical alteration after a LASIK procedure. The relative extent of biomechanical alteration focuses on depth, specifically the relative extent of anterior tissue that is modified during excimer laser surgery.[10] The anterior 40% of the cornea stroma has been found to have significantly greater cohesive tensile strength than the posterior cornea stroma,[26] and it is believed that removing this part of the stroma might induce a weakening process whereby beyond the threshold, ectasia results. In the study by Santhiago et al.,[10] the PTA as a screening metric for ectasia risk in eyes with normal topography achieved a sensitivity of 97% and a specificity of 89%. In patients with bilateral normal topography, a PTA more than 40 was found to be the most significant predictor of the risk for ectasia, with a higher OR than patient age, RSBT, or the ERSS score. The PTA has yet to be externally and independently evaluated in eyes with post-LASIK ectasia, and we believe we are the first to do so with this population of cases. In eyes with normal topography in our study, a PTA greater than 40 achieved a sensitivity of 33.3% and a specificity of 85.9%. Overall, the PTA was less predictive of ectasia than the ERSS and the SCORE Analyzer, with the lowest area under the ROC. Our results are limited by the small number of ectatic eyes with normal topography suitable for PTA analysis. Furthermore, we did not have measured flap thickness available, only the estimated flap thickness.

In Randleman et al.'s study to devise the ERSS,[4] the majority of cases were obtained through a literature review and the intended flap thickness had to be used in the analysis of most cases, with only 11.7% having a documented measured pachymetry. The flap thickness measurements used for our cases were also the intended flap thicknesses and not the measured ones. We acknowledge that in Santhiago et al.'s study of the PTA,[10] the PTA cutoff value

Table 6. Summary of specificity of the 3 scoring systems.

	All Eyes			Eyes with Normal Topography		
	Number (%)			Number (%)		
System	Normal Controls (n = 79)	Mean ± SD	Range	Normal Controls (n = 64)	Mean ± SD	Range
SCORE ≥0	79 (100.0)	−2.3 ± 0.9	−4.5, −0.1	64 (100.0)	−2.3 ± 0.9	−4.5, −0.1
PTA ≥40	NA	NA	NA	55 (85.9)	35.0 ± 4.7	26.1, 45.2
ERSS ≥4	63 (79.7)	2.0 ± 1.6	0, 6	58 (90.6)	1.5 ± 1.3	0.0, 5.0

ERSS = Ectasia Risk Score System; NA = not applicable; PTA = percent tissue altered; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer

Table 7. Specificity of the systems used in combination in eyes with normal topography (n = 64).

Systems	Specificity (%)	Eyes (n)
ERSS + SCORE	90.6	58
SCORE + PTA	85.9	55
ERSS + PTA	82.8	53
ERSS + SCORE + PTA	82.8	53
SCORE alone	100	64

ERSS = Ectasia Risk Score System; PTA = percent tissue altered; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer

was derived from the measured flap thicknesses. Ideally, in a validation study, the measured flap thickness data should be applied. We also acknowledge that it is possible that some cases in our series had unexpectedly thick flaps. However, a study of flap thickness in eyes with ectasia after LASIK[27] found that the measured flap thickness was not greater than that estimated in most eyes, showing that excessively thick flaps did not appear to be a major contributing factor to the pathogenesis of ectasia. Most studies of flap thickness accuracy and variability also found the actual flap was thinner than anticipated by the microkeratome plate markings.[28] In our study, 64.5% of our ectasia cases had flaps created with a microkeratome.

To further determine whether the sensitivity of the PTA was affected by the use of intended flap thickness in our study, we compared the flap thickness necessary to generate a PTA value of 40 with the intended flap thickness logged in our study in all false-negative PTA cases. The results of these supplementary data support the conclusion that the use of the measured flap thickness instead of the intended flap thickness would not have improved the overall sensitivity of PTA in this study.

In the studies of the formulation and validation of the PTA concept and threshold of more than or equal to 40, the preoperative minimum corneal thickness measurements were taken using US pachymetry.[10,11] In our study, the minimum corneal thickness was measured using the Orbscan IIz device, and this could account for variability in the sensitivity and specificity outcomes between studies because thinner or thicker corneas would affect PTA values for equivalent flap thicknesses and ablation depths.[29]

We also evaluated the eyes with a falsely negative PTA to determine whether age was a confounding factor accounting for the low sensitivity of PTA in our study. Patients with a false-negative PTA were not significantly younger than those in the control population or in all eyes with ectasia in the normal topography subgroup.

A system in which the measured flap thickness plays an integral role in predicting ectasia risk (eg, PTA) has inherent disadvantages. From a practical standpoint, the decision to perform LASIK has to be made preoperatively before the flap is created and cannot be made after it has been cut. The PTA risk scoring and cutoffs hinge on flap thicknesses that were measured after the flap was cut; however, the surgeon calculates the PTA preoperatively based on the flap thickness that he or she intends to create. This unpredictable discrepancy between the intended and eventual (measured) flap thickness is a practical drawback of the PTA.

The subgroup analysis of eyes with normal topography was performed to evaluate the sensitivity and specificity of the PTA and to directly compare its accuracy with that of the ERSS and the SCORE Analyzer. However, the sensitivity and specificity values obtained for the SCORE Analyzer and ERSS in this subgroup might not be an accurate representation of the true efficacy of the 2 systems and have to be interpreted with caution. The SCORE Analyzer was designed to identify at-risk corneas by combining Placido analysis with tomography, elevation, and pachymetric data. By excluding the topographies that were categorized as suspicious or abnormal by Placido criteria in this normal topography subgroup, the SCORE Analyzer is left to identify the other at-risk cases through tomography and thickness variations alone, which can result in a lower sensitivity. Similarly, for the ERSS, the scoring for topography in this subgroup would be zero or one (normal), resulting in a lower overall ERSS score. The sensitivity and specificity obtained with all eyes in this study are therefore better representations of the actual capabilities of the 2 systems than those obtained in the normal topography subgroup.

Table 8. The PTA in eyes that were false negative.

		Flap Thickness (μm)		
MK/FS (Platform)	PTA	Intended	Required	Difference
MK (Hansatome*)	36.0	110	129	19
MK (Hansatome*)	28.6	110	172	62
FS (Intralase†)	33.3	110	143	33
FS (Intralase†)	33.3	110	143	33
FS (Intralase†)	30.9	120	168	48
FS (Intralase†)	32.9	120	157	37
FS (Intralase†)	32.9	100	133	33
FS (Intralase†)	34.0	100	128	28

Difference = flap thickness overcut required for a PTA of ≥40; FS = femtosecond laser; MK = microkeratome
*Bausch & Lomb, Inc.
†Abbott Medical Optics, Inc.

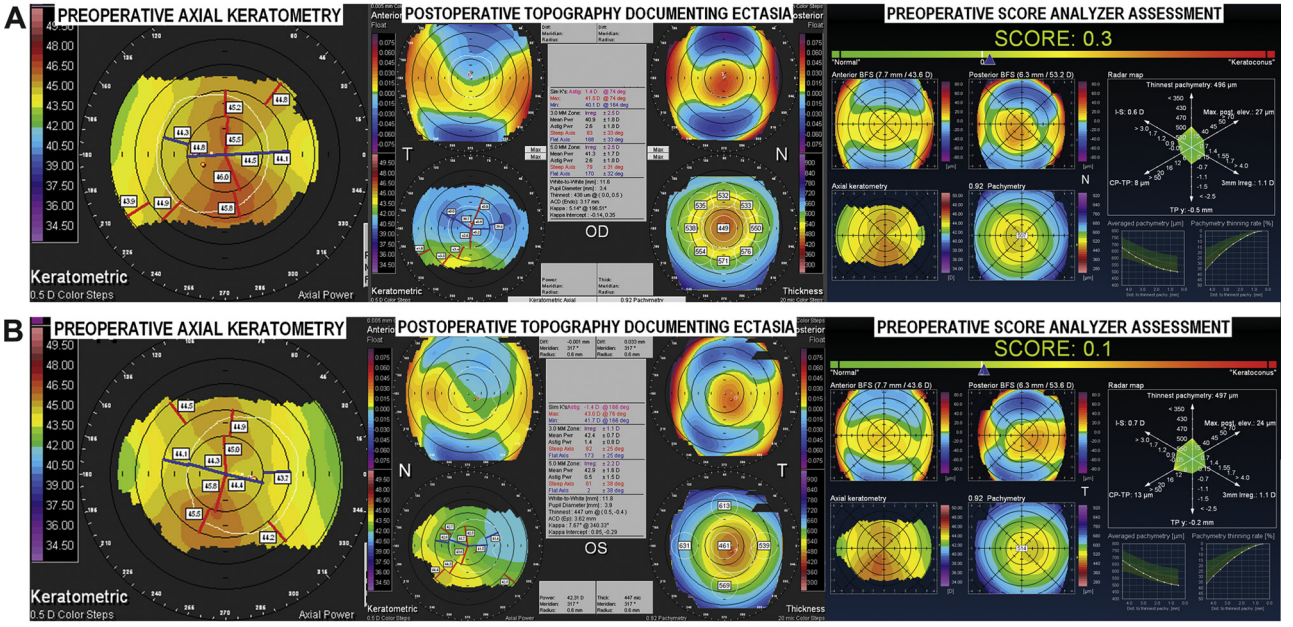


Figure 6. *A* and *B*: Preoperative and postoperative topographies and SCORE Analyzer assessment of the right eye (*A*) and left eye (*B*) of a 40-year-old white man with bilateral ectasia. Both eyes were scored 1 by ERSS topographic criteria (ERSS = Ectasia Risk Score System; SCORE = Screening Corneal Objective Risk of Ectasia).

In our study, when the 3 systems were used in combination in the normal topography subgroup, greater sensitivity in predicting ectasia risk was achieved, but at the expense of specificity. An improved sensitivity at the expense of specificity would be unacceptable in practical terms, as it would mean unnecessarily excluding a large group of patients from safely benefiting from the life-changing benefits of LASIK.

The current ERSS classification of topography is based purely on Placido maps and indices, the interpretation of which is subjective, and this is a disadvantage that our study underlines. In the light of our findings, we suggest that the current topographic criteria in the ERSS be replaced with a system that provides more objectivity to topography and tomography interpretation. Work is in progress to incorporate the SCORE Analyzer into the ERSS to generate a more objective, sensitive, and specific risk scoring system for ectasia.

Two eyes of the same patient (Case 4) were passed as negative or at low risk for ectasia by all 3 systems, indicating the existence of other unidentified factors in ectasia development. This and the overall findings of our study show that some eyes susceptible to ectasia might be undetectable by current methods. Improving the sensitivity and specificity of detection in such cases should be the focus of future work, with epithelial thickness analysis and corneal biomechanical measures possibly bridging the gap. In a study by Reinstein et al.,[30] epithelial thickness measurements using very-high-frequency (VHF) digital US were found to be useful in keratoconus screening. The VHF digital US epithelium model was able to pick up keratoconus in half of the normal fellow eyes of patients with unilateral keratoconus in the study. This concept might prove useful as an adjunctive tool for ectasia risk screening in the future.

The SCORE Analyzer and the PTA were devised as ectasia risk analysis systems for each eye, not each patient. In clinical practice, unilateral positivity (1 eye positive while the other eye remains negative for the considered scoring system) might affect the decision for the negative eye,

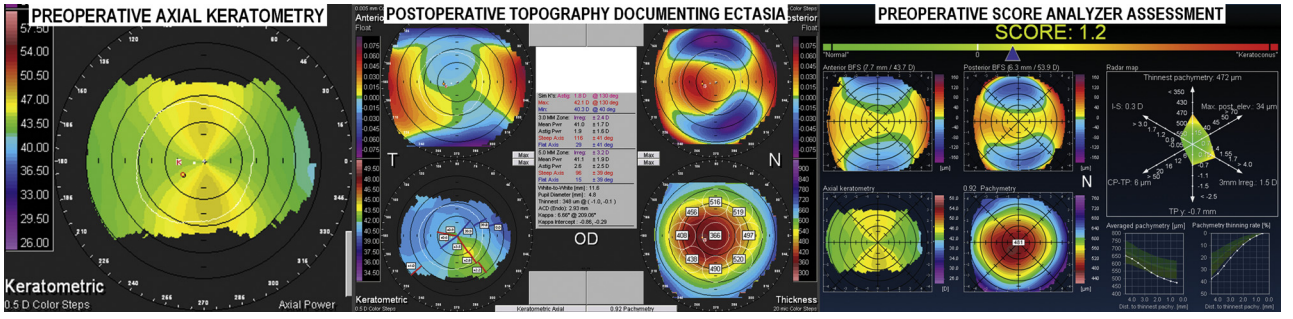


Figure 7. The right eye of a patient who developed ectasia 2 years after LASIK, with the preoperative Placido topography score of 1 by ERSS topographic criteria (ERSS = Ectasia Risk Score System; LASIK = laser in situ keratomileusis; SCORE = Screening Corneal Objective Risk of Ectasia).

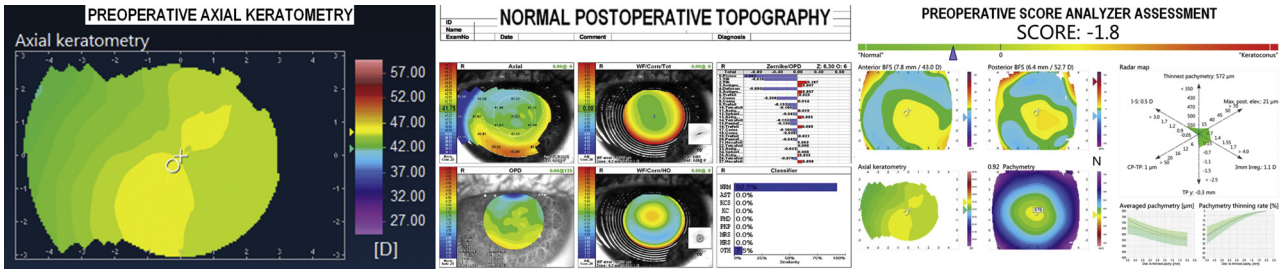


Figure 8. Preoperative and postoperative topographies of a control eye (SCORE = Screening Corneal Objective Risk of Ectasia).

although at present no specific guidelines exist in such cases. A bilateral or per-patient analysis could therefore alter the sensitivity and specificity of these 2 systems and the ERSS in any given study. This is beyond the scope of our paper, and it could be the basis of specifically designed future work.

Our study has limitations. A larger number of cases in the ectasia group would have made this study statistically robust. However, ectasia after LASIK is rare[2] and it was difficult for us to gather more cases. It was only through a multicenter collaborative effort involving 8 countries that we managed to gather the 31 cases described here, with each coauthor contributing a few cases from his or her practice. We were also limited by the availability of the Orbscan IIz topographer examination (.exm) files required to retrospectively run the SCORE Analyzer to generate the SCORE number. A number of ectasia cases identified did not have the .exm files available or had preoperative topographies performed using topography systems other than the Orbscan and hence could not be included.

It was difficult to obtain an exact contemporaneous population of controls from the same centers as the patients with ectasia with the necessary data and postoperative follow-up after LASIK; therefore, we opted to use controls obtained from a single center instead. Another limitation is the flaps in our control population were all created with the femtosecond laser, while in the ectasia group, microkeratomes and femtosecond lasers were used for this purpose, creating a confounding variable by virtue of the differences in the predictability of flap thickness in the 2 groups. We were also limited by the heterogeneity of ectasia cases referred from multiple surgeons and centers. Due to the retrospective nature of the study and its attendant difficulties, it was not possible to obtain certain clinical and surgical details in the cases. None of the cases had intraoperative pachymetry available, and it was not possible to elicit a clinical history of excessive eye rubbing after LASIK or atopy or a family history of ectatic corneal disorders in most patients. The ectatic eyes included in the study were limited to those with Orbscan IIz topographies for testing with the SCORE Analyzer. Topographic systems using other technologies, such as Scheimpflug, dual Scheimpflug, and optical coherence tomography, were not included and should be the subject of evaluation in further studies on ectasia.

In conclusion, our study showed that a SCORE Analyzer value greater than or equal to 0 was more predictive of ectasia than a PTA value greater than or equal to 40 and an ERSS value greater than or equal to 4. A SCORE Analyzer value greater than or equal to 0 achieved the best specificity (100%) and ERSS value greater than or equal to 4, the best sensitivity (67.7%). In eyes with normal topography, a combination of all 3 risk-assessment systems appeared to be most sensitive in predicting the risk for ectasia, but at the expense of specificity. Given the low sensitivity observed with the PTA in this independent population of cases, further studies are required to validate the PTA as a screening metric for ectasia.

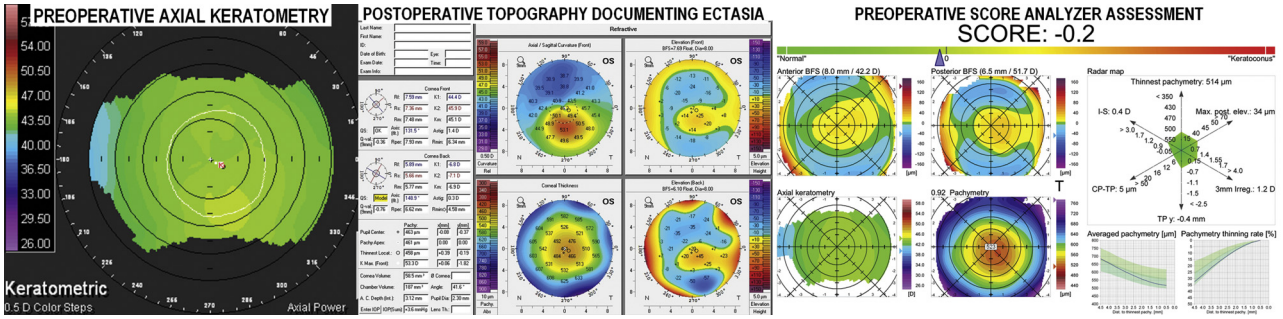


Figure 9. The left eye of a 26-year-old woman with bilateral ectasia in whom all 3 systems scored both eyes as low risk or negative risk for ectasia. Preoperative topography was scored a 1 by ERSS topographic criteria (ERSS = Ectasia Risk Score System; SCORE = Screening Corneal Objective Risk of Ectasia).

Table 9. Optimizing the threshold value for the SCORE Analyzer.

SCORE Value	Sensitivity	Specificity	PPV	NPV	Sens + Spec	Accuracy
−1.006	0.935	0.911	0.806	0.973	1.847	0.918
−0.958	0.935	0.924	0.829	0.973	1.860	0.927
−0.951	0.935	0.937	0.853	0.974	1.872	0.936
−0.943	0.935	0.949	0.879	0.974	1.885	0.945
−0.853	0.935	0.962	0.906	0.974	1.898	0.955
−0.800	0.903	0.962	0.903	0.962	1.865	0.945
−0.700	0.839	0.962	0.897	0.938	1.801	0.927
−0.665	0.839	0.975	0.929	0.939	1.813	0.936
−0.600	0.806	0.975	0.926	0.928	1.781	0.927
−0.500	0.742	0.975	0.920	0.906	1.717	0.909
−0.428	0.742	0.987	0.958	0.907	1.729	0.918
−0.400	0.677	0.987	0.955	0.886	1.665	0.900
−0.200	0.645	0.987	0.952	0.876	1.633	0.891
−0.062	0.645	1.000	1.000	0.878	1.645	0.900
0.000	0.613	1.000	1.000	0.868	1.613	0.891
0.100	0.548	1.000	1.000	0.849	1.548	0.873
0.200	0.452	1.000	1.000	0.823	1.452	0.845
0.300	0.387	1.000	1.000	0.806	1.387	0.827
1.100	0.355	1.000	1.000	0.798	1.355	0.818

NPV = negative predictive value; PPV = positive predictive value; SCORE = Screening Corneal Objective Risk of Ectasia Analyzer; Sens + Spec = sensitivity and specificity

WHAT WAS KNOWN

- Risk assessment systems have been devised to objectively assess suitability for refractive surgery. The ERSS and PTA were designed to identify patients at higher risk for developing post-LASIK ectasia.
- The SCORE Analyzer is a topographic–tomographic system to detect early keratoconus. The efficacy of the SCORE Analyzer and other topographic scoring systems has been evaluated in eyes with forme fruste keratoconus; however, these systems have not been retrospectively tested in eyes that developed ectasia after LASIK.

WHAT THIS PAPER ADDS

- All 3 systems were imperfect tools for predicting the risk for ectasia.
- A SCORE value greater than or equal to 0 was the most predictive of ectasia and achieved the highest specificity.
- In eyes with normal topography, use of a combination of the 3 systems yielded greater sensitivity in predicting ectasia risk, but at the expense of specificity.

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Disclosures: *Drs. Gatinel and Saad are consultants to Bausch & Lomb Technolas. None of the other authors has a financial or proprietary interest in any material or method mentioned.*

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