

Stability of LASIK in Topographically Suspect Keratoconus Confirmed Non-keratoconic by Artemis VHF Digital Ultrasound Epithelial Thickness Mapping: 1-year Follow-up

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ABSTRACT

PURPOSE: To determine the 1-year stability of LASIK in corneas with topographic suspect keratoconus confirmed as non-keratoconic by epithelial thickness mapping.

METHODS: This was a retrospective case/control comparative study. Eyes suspected of keratoconus using criteria based mainly on Atlas (Carl Zeiss Meditec AG) and Orbscan II (Bausch & Lomb) topography were scanned by Artemis very high-frequency digital ultrasound (ArcScan Inc). Keratoconus was confirmed if the epithelial thickness profile showed relative epithelial thinning coincident with an eccentric posterior elevation best-fit sphere apex. Laser in situ keratomileusis was performed in all eyes where keratoconus was excluded by finding relatively thicker epithelium or not finding localized thinning over the topographically suspected cone. Patients were followed for 1 year after LASIK. A control group was generated matched within 0.50 diopter (D) for sphere, cylinder, and spherical equivalent refraction (SEQ) to compare refractive stability.

RESULTS: The average change in SEQ between 3 and 12 months was -0.10 ± 0.30 D for the suspect keratoconus group and -0.10 ± 0.28 D for controls. No statistically significant difference in shift from 3 months to 12 months in SEQ or cylinder between groups was noted. No statistically significant change in best spectacle-corrected visual acuity between groups was noted, with no eye losing 2 lines and 5% in the suspect keratoconus group and 2% of controls losing 1 line. No cases of ectasia were observed in either group.

CONCLUSIONS: Suspect keratoconus, confirmed to be non-keratoconic by epithelial thickness profile criteria demonstrated equal stability to control eyes 1 year after LASIK. Epithelial thickness profiles may enable LASIK to be performed in eyes that would otherwise have been excluded due to topographic suspect keratoconus. Further follow-up is being carried out. [*J Refract Surg.* 2009;25:569-577.] doi:10.3928/1081597X-20090610-02

Performing LASIK on undiagnosed keratoconic eyes is a major concern and has been identified as the leading cause of ectasia after corneal laser refractive surgery.¹⁻¹³ The detection of keratoconus, particularly early or mild keratoconus, is therefore a major safety issue. Many different methods have been suggested to discriminate between normal and keratoconus suspect eyes; however, front-surface corneal topography remains the current standard for keratoconus screening.¹⁴⁻¹⁶

Ideally, surgeons need a diagnostic technique that would render a definitive diagnosis of keratoconus with near 100% specificity and sensitivity. If keratoconus was present, corneal refractive surgery would not be performed, whereas if keratoconus was excluded, either photorefractive keratectomy (PRK) or LASIK could be performed safely. If the diagnostic test was not sensitive enough, some keratoconic eyes will be wrongly classified as normal. This might occur for some early cases of keratoconus, which might not show any changes on front-surface corneal topography. These eyes are at greater risk for developing ectasia after corneal refractive surgery. On the other hand, if the diagnostic test was not specific enough, some normal eyes will be wrongly diagnosed as keratoconus and good candidates would be denied the benefits of corneal refractive surgery.

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Dr Reinstein is a consultant for Carl Zeiss Meditec AG (Jena, Germany) and has a proprietary interest in the Artemis technology (ArcScan Inc, Morrison, Colo) through patents administered by the Cornell Research Foundation, Ithaca, NY. The remaining authors have no proprietary or financial interest in the materials presented herein.

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We suggested the use of epithelial thickness profile maps obtained by the Artemis very high-frequency (VHF) digital ultrasound arc-scanner (ArcScan Inc, Morrison, Colo) as a new diagnostic technique, with the aim to provide both higher specificity and sensitivity to diagnose early cases of keratoconus when topography is equivocal.^{17,18} This screening method is based on the fact that the corneal epithelium has the ability to alter its thickness profile to re-establish a smooth, symmetrical optical surface and either partially or totally mask the presence of an irregular stromal surface from front-surface topography.¹⁹ Therefore, thinning of the epithelium coincident with an eccentric posterior elevation best-fit sphere (BFS) apex would indicate the presence of keratoconus, whereas finding thicker epithelium and/or a lack of localized thinning over an area of topographic steepening would be inconsistent with keratoconus. By using epithelial thickness mapping, we demonstrated cases where a normal epithelial thickness profile excluded keratoconus despite suspect front-surface topography, as well as cases where localized epithelial thinning over an eccentric posterior elevation BFS apex indicated a diagnosis of keratoconus despite apparently normal front-surface topography.¹⁷

The purpose of this study was to examine the refractive stability, safety, and cylinder vector change 1 year after LASIK in eyes with suspect keratoconus, where the diagnosis of keratoconus was excluded by epithelial thickness mapping, and compare them to a matched group of control eyes with no signs of suspected keratoconus.

PATIENTS AND METHODS

This retrospective case/control study compared patients seeking refractive surgery at the London Vision Clinic between May 2003 and August 2006. A complete ocular examination was performed to determine patient candidacy for refractive surgery. The preoperative assessment of all patients included manifest refraction, logMAR best spectacle-corrected visual acuity (BSCVA) (CSV-1000; Vector Vision Inc, Greenville, Ohio), and cycloplegic refraction using one drop of Tropicamide 1% (Alcon Laboratories UK Ltd, Hemel Hempstead, United Kingdom). Topography was assessed using the TMS (Tomey Ltd, Nagoya, Japan) until July 2005, and the Atlas 995 corneal topography system (Carl Zeiss Meditec AG, Jena, Germany) after July 2005. Tomography was assessed using Orbscan II (Bausch & Lomb, Salt Lake City, Utah). Dynamic pupillometry was done using the Procyon P2000 pupillometer (Haag-Streit, Bern, Switzerland). Wavefront assessment was performed using the WASCA aberrometer (Carl Zeiss Meditec AG). Single-point corneal thickness minimum was determined with the Corneo-Gage Plus (50

MHz) handheld ultrasound pachymeter (Sonogage, Cleveland, Ohio) from 10 consecutive central corneal measurements. Intraocular pressure (IOP) was measured using a Goldmann applanation tonometer (AT 900 Applanation Tonometer, Haag Streit).

PROTOCOL FOR KERATOCONUS SCREENING

During preoperative screening, the following parameters were considered to assess a patient's suitability for corneal laser refractive surgery and, in particular, to screen for keratoconus. Front- and back-surface topography were given the most weight in the keratoconus screening process. A very low threshold for suspicion of keratoconus was employed to include early and/or mild keratoconus. All eyes that demonstrated any of the following three topographic characteristics were deemed suspect keratoconus, without relying on specific limits for inferior steepening or other topographic indices. Inferior steepening on topography can be artificially indicated if the scan is misaligned.²⁰ For this reason, topography was repeated until the best possible examination was obtained.

1. Inferior steepening, asymmetric bowtie, or skew bowtie on front-surface corneal topography.

2. Eccentric and/or unusually high posterior elevation over the BFS apex using default 10-mm fit zone.

3. Coincidence of posterior elevation BFS apex, anterior elevation BFS apex, and minimum corneal thickness.

The following parameters were also considered and a subjective clinical judgment was made by assessing the sum of the weighted contributions of these factors, in addition to topography. The weighting for each parameter was considered on a graded scale relative to well-established normal ranges rather than using parameter-specific limits for classifying suspicion of keratoconus.

4. Steep keratometry.

5. Against-the-rule or oblique astigmatism, or right eye versus left eye asymmetry in axes.

6. High degree of astigmatism.

7. Thin corneal thickness.

8. Reduced BSCVA.

9. Reduced contrast sensitivity.

10. Family history of keratoconus.

11. Historical refractive instability with particular attention to increasing cylinder and/or rotation of the axis.

12. Young age.

13. High level of ocular higher order aberrations, in particular, vertical coma.

14. Automated indices derived from computerized front-surface corneal topography (ie, the PathFinder Corneal Analysis program on the Atlas).

15. Right eye versus left eye asymmetry in minimum corneal thickness, keratometry, or refraction.

16. Asian or Indian ethnicity raised suspicion of keratoconus.²¹

17. History of eye rubbing and atopy raised suspicion of keratoconus.

Since the end date for this study, we now also routinely obtain measurements with the:

18. Ocular Response Analyzer (Reichert Inc, Depew, NY) (low values of corneal hysteresis and corneal resistance factor are suggestive of keratoconus).^{22,23}

19. Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) (provides indices based on topography and corneal thickness progression).²⁴

Patients for whom a diagnosis of keratoconus was evident and unequivocal based on our keratoconus screening protocol were rejected for corneal refractive surgery and did not require an Artemis epithelial thickness profile to confirm the presence of keratoconus. Corneal collagen cross-linking was offered to patients appropriately selected according to BSCVA and minimum corneal thickness as measured using Artemis VHF digital ultrasound.

Patients deemed suspect keratoconus from the screening criteria underwent Artemis VHF digital ultrasound scanning. The Artemis epithelial thickness profile was used to confirm or exclude the diagnosis of keratoconus according to our criteria previously published^{17,18} and briefly described in the Introduction. The suspect keratoconus group included eyes that could potentially have been deemed suitable for surgery with a more relaxed keratoconus screening protocol; for example, there were cases where the front-surface topography was normal but an eccentric posterior surface BFS apex raised suspicion. Eyes for which a diagnosis of keratoconus was confirmed were rejected for surgery, and eyes where a diagnosis of keratoconus was excluded were deemed suitable for surgery.

Patients for whom there was no suspicion of keratoconus according to the screening criteria were deemed suitable for corneal laser refractive surgery without having an Artemis scan.

RETROSPECTIVE GROUP SELECTION

Patients with ocular pathologies including keratoconus, pellucid marginal degeneration, corneal dystrophies, corneal scars, and previous ocular surgery were also excluded from the study.

The suspect keratoconus group was retrospectively generated to include all myopic eyes that underwent LASIK during the study period for which an Artemis scan had been required to rule out keratoconus. Eyes with hyperopia or mixed cylinder were not included in

the outcomes analysis. For the purposes of this study, eyes that underwent PRK were excluded as eyes that underwent LASIK would be expected to be the most at-risk for developing ectasia. Photorefractive keratectomy was chosen instead of LASIK for cases where the residual stromal bed thickness was close to the lower limit of 250 μm and in all cases where the minimum corneal thickness was below 465 μm .

Having identified the suspect keratoconus group, a control group was selected from the same database of normal myopic eyes that underwent LASIK at the London Vision Clinic for which an Artemis scan was not required and follow-up data at 3 and 12 months postoperative were available. A control eye was found to match each eye in the suspect keratoconus group for sphere and cylinder within 0.50 D. If there were multiple possible control eyes, the eye to use for the study was selected at random. Control eyes were not matched for any other parameter, including axis of astigmatism and age.

EPITHELIAL THICKNESS PROFILE MAPPING USING ARTEMIS VHF DIGITAL ULTRASOUND ARC-SCANNING

The Artemis VHF digital ultrasound system has been previously described in detail.²⁵⁻²⁹ Artemis scanning provides very high resolution ultrasound B-scans of the cornea showing clear delineation of the epithelial surface, Bowman's surface, and the back-surface of the cornea, providing the major advantage of producing three-dimensional thickness mapping of each individual layer over a 10-mm corneal diameter with approximately 1- μm precision.²⁶ An epithelial thickness profile was obtained for all patients included in the suspect keratoconus group using Artemis VHF digital ultrasound scanning.

SURGICAL PROCEDURE

All procedures were performed by the same surgeon (D.Z.R.). All patients underwent LASIK using the MEL 80 excimer laser (Carl Zeiss Meditec AG). The CRS-Master software platform (Carl Zeiss Meditec AG) was used to generate the ablation profiles (version 1.1 for treatments before November 8, 2004 and version 1.3 after this date). The Hansatome microkeratome (Bausch & Lomb, St Louis, Mo) was used for all patients treated before June 22, 2005 and the Hansatome zero compression microkeratome (Bausch & Lomb) was used for all patients treated after this date. Either the 160- or the 180- μm head was used. Either the 8.5- or the 9.5-mm ring was used. All procedures were performed without intraoperative complications.

STATISTICAL ANALYSIS

Outcome measures were calculated according to the standardized guidelines by Eydeman et al,³⁰ includ-

TABLE 1
Preoperative Data for the Suspect Keratoconus and Control Groups

	Mean ± Standard Deviation (Range)		P Value
	Suspect Keratoconus Group	Control Group	
Age (y)	37 ± 10 (23 to 63)	42 ± 11 (22 to 69)	.002
SEQ (D)	-3.78 ± 1.87 (-0.75 to -9.75)	-3.79 ± 1.88 (-0.75 to -9.75)	.989
Sphere (D)	-3.27 ± 1.95 (0.00 to -9.75)	-3.24 ± 1.97 (0.00 to -9.75)	.986
Cylinder (D)	-1.02 ± 0.74 (0.00 to -3.25)	-1.02 ± 0.74 (0.00 to -3.25)	.984
Corneal thickness (μm)	534 ± 29 (477 to 610)	537 ± 27 (487 to 602)	.527
IOP (mmHg)	14.0 ± 2.0 (9 to 19)	14.5 ± 2.3 (8 to 20)	.107

SEQ = spherical equivalent refraction, IOP = intraocular pressure
 P value < .05 shows statistically significant difference between groups by t test.

ing cylinder vector analysis. Safety, refraction stability, change in spherical equivalent refraction between 3 and 12 months, and cylinder vector change from 3 to 12 months were analyzed for both the suspect keratoconus and control groups. The Student *t* test was used to compare outcomes between groups. A *P* value of < .05 was deemed statistically significant. Microsoft Excel 2003 (Microsoft Corp, Redmond, Wash) was used for data entry and statistical analysis.

RESULTS

POPULATION

During the study period, 1532 consecutive myopic eyes were screened for suitability for corneal refractive surgery. Of these 1532 eyes, 136 (8.9%) were classified as suspect keratoconus according to the criteria described earlier. Of the 136 suspect keratoconus eyes, Artemis epithelial thickness profile mapping revealed localized epithelial thinning in the region of the suspected cone in 22 (16%) eyes, and were therefore excluded from corneal refractive surgery due to suspected keratoconus. The remaining 114 (84%) eyes demonstrated a normal epithelial thickness profile and were deemed suitable for corneal laser refractive surgery, of which 90 eyes of 48 patients underwent LASIK and 24 eyes of 13 patients underwent PRK. The suspect keratoconus group was defined as the 90 eyes that underwent LASIK. Only 1 eye was included for 6 patients in the suspect keratoconus group. The fellow eye was excluded due to mixed cylinder in 3 patients and hyperopia in 1 patient, and the fellow eye was treated with PRK in 1 patient and in 1 patient the fellow eye was left untreated as the refraction of $-1.75 -0.50 \times 13$ was suitable for monovision. A matched control group was randomly chosen as described earlier, which is referred to as the control group.

The median follow-up period after the primary treatment was 12.8 months for the suspect keratoconus group and 12.5 months for the control group. Five (5.6%) eyes of three patients of the suspect keratoconus group had not attended 12-month follow-up. Of these, three eyes of two patients had attended a 6-month appointment, whereas one patient had not returned to the clinic since the 1-week follow-up. Of the two patients (three eyes) who had attended a 6-month appointment, sphere and cylinder were stable within 0.25 D for all three eyes between 3 and 6 months and all had gained one line of BSCVA. Attempts have been made to contact each of these three patients. Currently, one patient has been unavailable to come to London for follow-up, and the remaining two patients have not yet been successfully traced. All 90 eyes of the control group had attended 12-month follow-up.

Table 1 shows the mean, standard deviation, and range of age, spherical equivalent refraction, cylinder, handheld ultrasound pachymetry, and Goldmann IOP for the suspect keratoconus group and the control group.

The mean difference in sphere between each pair of matched eyes was $+0.01 \pm 0.09$ D (range: -0.25 to $+0.40$ D). The mean difference in cylinder between each pair of matched eyes was 0.00 ± 0.16 D (range: -0.50 to $+0.50$ D). The mean difference in spherical equivalent refraction between each pair of matched eyes was $+0.00 \pm 0.11$ D (range: -0.25 to -0.40 D). No statistically significant difference in sphere ($P=.986$), cylinder ($P=.984$), spherical equivalent refraction ($P=.989$), handheld ultrasound pachymetry ($P=.527$), or Goldmann IOP ($P=.107$) was noted. However, the higher average age of the control group was statistically significant ($P=.002$).

A 160-μm microkeratome head was used for all eyes in the suspect keratoconus group. The 160-μm head was used for 86 (96%) eyes and a 180-μm head was

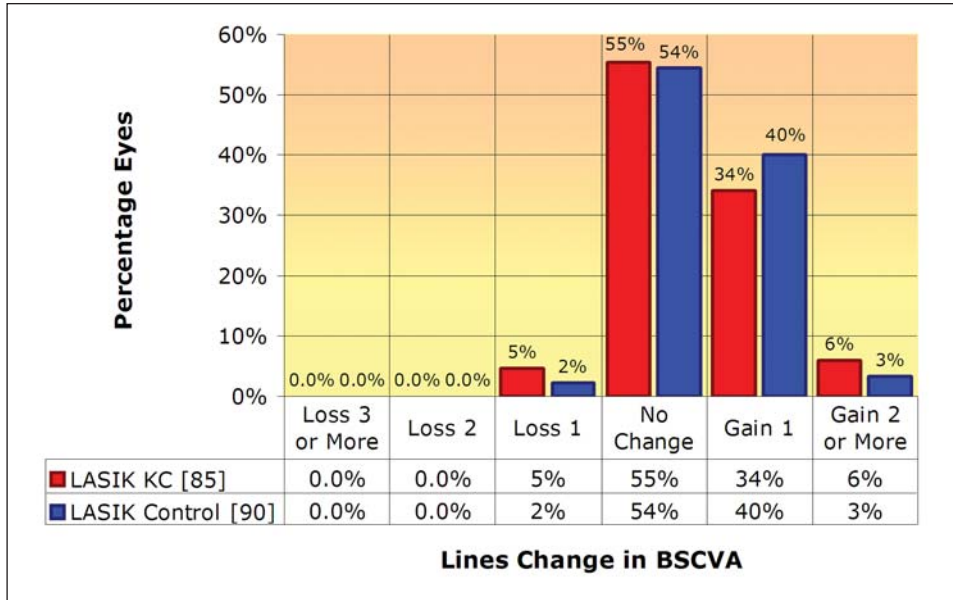


Figure 1. Histogram showing the change in logMAR lines of best spectacle-corrected visual acuity (BSCVA) 12 months after LASIK for the suspect keratoconus (KC) group and control group. Percentages were calculated for 85 eyes with at least 12 months' follow-up for the suspect keratoconus group and for 90 eyes for the control group. No eyes lost 2 or more lines of BSCVA in either group. Five percent of eyes lost 1 line for the suspect keratoconus group and 2% of eyes lost 1 line for the control group.

used for 4 (4%) eyes of the control group. An 8.5-mm microkeratome ring was used for 43 (48%) eyes and an 9.5-mm ring was used for 47 (52%) eyes of the suspect keratoconus group. A 8.5-mm ring was used for 32 eyes (36%) and a 9.5-mm ring was used for 58 eyes (64%) of the control group.

SAFETY

The change in BSCVA lines for both groups is shown in Figure 1. No eyes lost two or more lines of BSCVA in either group. Five percent of eyes lost one line for the suspect keratoconus group and 2% of eyes lost one line for the control group. No statistically significant difference in safety measured in gain and loss of logMAR BSCVA between the suspect keratoconus and control groups was noted ($P=.736$).

STABILITY OF SPHERICAL EQUIVALENT REFRACTION

Figure 2 and Table 2 show the stability of spherical equivalent refraction for the suspect keratoconus and control groups preoperatively and 1 day, 1 week, and 1, 3, 6, and 12 months postoperatively. In the suspect keratoconus group, mean spherical equivalent refraction was -0.14 ± 0.47 D (range: -1.66 to $+0.75$ D) 3 months after LASIK and -0.23 ± 0.47 D (range: -1.66 to $+0.88$ D) 12 months after LASIK. In the control group, mean spherical equivalent refraction was -0.10 ± 0.39 D (range: -0.90 to $+1.25$ D) 3 months after LASIK and -0.20 ± 0.42 D (range: -1.15 to $+1.50$ D) 12 months after LASIK. No statistically significant difference in mean spherical equivalent refraction between the two groups at any time points was noted ($P=.537$ at 3 months, $P=.628$ at 12 months).

The mean change in spherical equivalent refraction

between 3 and 12 months was -0.10 ± 0.30 D (range: -0.88 to $+0.88$ D) in the suspect keratoconus group and -0.10 ± 0.28 D (range: -0.88 to $+0.63$ D) in the control group. The myopic shift between 3 and 12 months was statistically significant for both groups ($P=.010$ for the suspect keratoconus group and $P=.001$ for the control group). No statistically significant difference in the change of spherical equivalent refraction between 3 and 12 months for the keratoconus group and the control group was noted ($P=.994$). The percentage of eyes with a change in spherical equivalent refraction >0.50 D between 3 and 12 months was 6.2% in the suspect keratoconus group and 6.7% in the control group. Specifically, the percentage of eyes for which there was a myopic shift >0.50 D in spherical equivalent refraction was 3.1% in the suspect keratoconus group and 5.6% in the control group.

VECTOR STABILITY OF CYLINDER

Figure 3 shows double angle plots for preoperative cylinder, 3 and 12 months cylinder, and the vector change in cylinder for both the suspect keratoconus and control groups.

In the suspect keratoconus group, mean magnitude of cylinder was -0.35 ± 0.34 D (range: 0.00 to 1.50 D) 3 months after LASIK and -0.40 ± 0.40 D (range: 0.00 to 2.00 D) 12 months after LASIK. In the control group, mean magnitude of cylinder was -0.38 ± 0.40 D (range: 0.00 to 2.50 D) 3 months after LASIK and -0.41 ± 0.41 D (range: 0.00 to 2.25 D) 12 months after LASIK. No statistically significant difference in the mean magnitude of cylinder between groups at 3 or 12 months was noted ($P=.572$ and $P=.880$, respectively).

The mean vector change in cylinder between 3

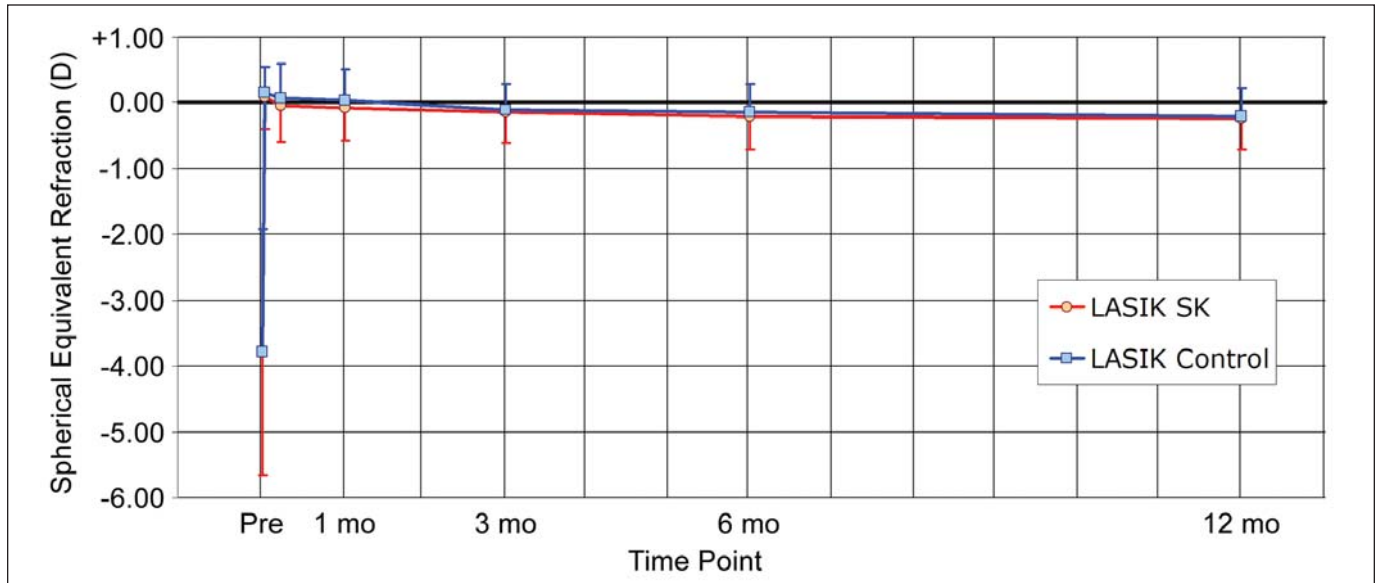


Figure 2. The stability of the suspect keratoconus group (SK) and control group was plotted as the mean (data points) and standard deviation (error bars) of the spherical equivalent refraction adjusted for the intended postoperative spherical equivalent refraction for all eyes measured at each time point. The SK group data are shown in red with downward standard deviation bars only, whereas the control group data are shown in blue with upward standard deviation bars only.

TABLE 2

Spherical Equivalent Refraction at Each Follow-up for the Suspect Keratoconus and Control Groups

	Mean ± Standard Deviation (Range)						
	Preop	1 Day	1 Week	1 Month	3 Months	6 Months	12 Months
Suspect keratoconus group	-3.78 ± 1.87 (-0.75 to -9.75)	+0.08 ± 0.49 (-1.25 to +1.45)	-0.04 ± 0.55 (-1.25 to +1.00)	-0.07 ± 0.51 (-1.54 to +1.00)	-0.14 ± 0.47 (-1.66 to +0.75)	-0.21 ± 0.50 (-1.79 to +1.00)	-0.23 ± 0.47 (-1.66 to +0.88)
Number of eyes	90	63	41	67	68	61	85
Control group	-3.79 ± 1.88 (-0.75 to +9.75)	+0.15 ± 0.38 (-1.00 to +0.83)	+0.07 ± 0.51 (-0.63 to +2.50)	+0.03 ± 0.48 (-0.63 to +2.25)	-0.10 ± 0.39 (-0.90 to +1.25)	-0.14 ± 0.42 (-0.88 to +1.38)	-0.20 ± 0.42 (-1.15 to +1.50)
Number of eyes	90	39	73	74	90	77	90
P value	.989	.450	.253	.229	.537	.375	.628

P value <.05 shows statistically significant difference between at each time point by t test.

and 12 months after LASIK was 0.28 ± 0.26 D (range: 0.00 to 1.21 D) in the suspect keratoconus group and 0.27 ± 0.23 D (range: 0.00 to 1.50 D) in the control group. The vector change between 3 and 12 months was not statistically significant within either group ($P=.159$ for the suspect keratoconus group, $P=.445$ for the control group). No statistically significant difference between groups in cylinder vector change between 3 and 12 months was noted ($P=.698$).

The mean error of magnitude 12 months after LASIK was -0.04 ± 0.31 D (range: -0.75 to $+1.00$ D) for the suspect keratoconus group and -0.03 ± 0.31 D (range: -0.75 to $+1.50$ D) for the control group. No statistically significant difference in mean error of magnitude

between groups at 12 months was noted ($P=.800$).

The mean error of axis at 12 months after LASIK was $+2.70 \pm 30.1^\circ$ (range: -84° to 85°) for the suspect keratoconus group and $-1.16 \pm 29.3^\circ$ (range: -85° to 87°) for the control group. No statistically significant difference in mean error of axis between groups at 12 months was noted ($P=.734$).

DISCUSSION

We found that suspect keratoconus eyes diagnosed as non-keratoconic by epithelial thickness profile mapping demonstrated equal safety, stability of spherical equivalent refraction, and stability of cylinder by vector analysis as control eyes 12 months after LASIK.

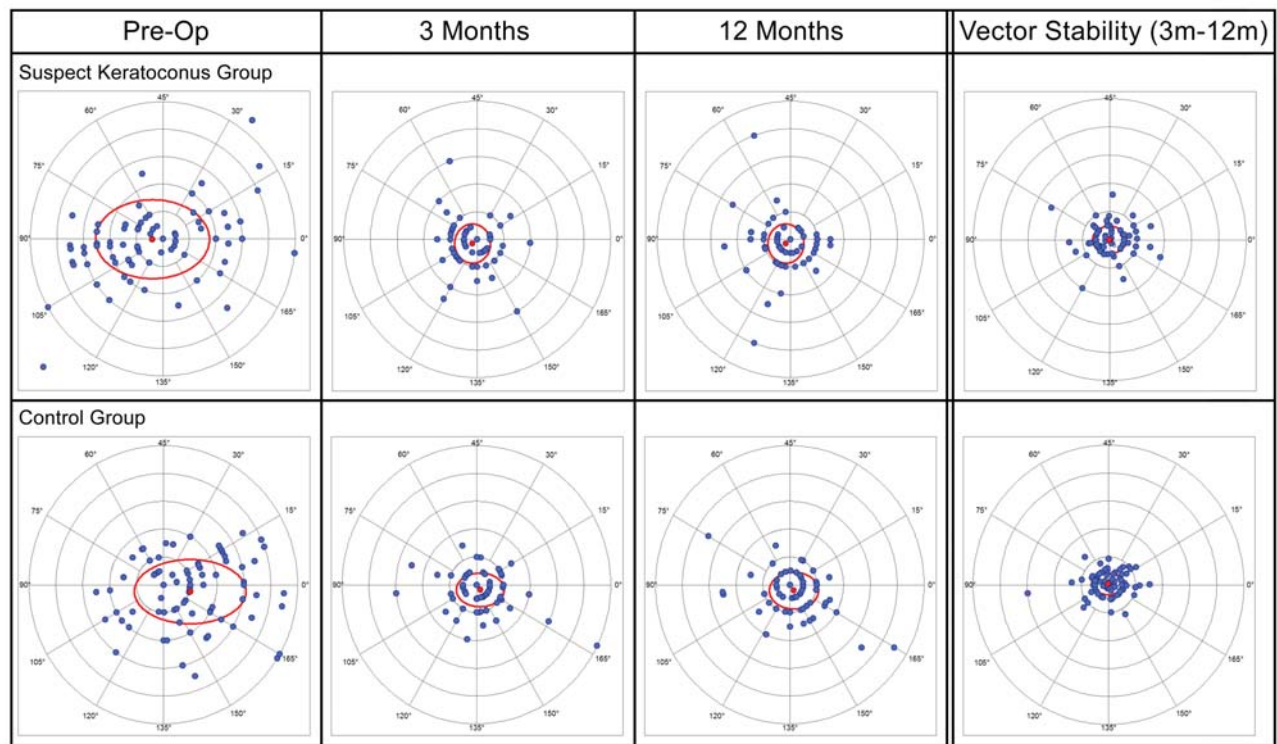


Figure 3. Double angle plots showing the distribution of the preoperative cylinder, cylinder at 3 and 12 months, and cylinder vector change between 3 and 12 months (m) for the suspect keratoconus and control groups. The centroid (red dot) and a standard deviation ellipse (red line) are displayed on each double angle plot. The rings are set out in 0.50-diopter (D) steps; therefore, the innermost ring is 0.50 D and the outside ring is 2.50 D. No statistically significant difference in the cylinder vector change between the two groups was noted.

This lends support to the hypothesis that epithelial thickness profiles can be used to screen for keratoconus in equivocal cases.

No cases of ectasia had been observed in the suspect keratoconus group to date for the LASIK or PRK group. A 95% confidence interval of a proportion for this study population puts the expected percentage of observed cases of ectasia between 0 and 5.4%. Therefore, the statistical power of the current study is relatively low and a larger population is needed to improve the reliability of the result. We are continuing to recruit patients and intend to report the stability of a larger population and over a longer follow-up period in the future.

Another weakness of the current study is the relatively short follow-up period. Randleman³¹ previously reported in a study of 43 ectasia cases that ectasia was diagnosed on average 16.3 months after LASIK, varying from 1 to 45 months, with 50% of cases being within the first 12 months. Other cases of ectasia occurring more than 24 months after surgery have been reported.^{32,33} Therefore, it is possible that some eyes in this study could develop ectasia after the 12-month time point reported. Also, the longest follow-up in this study was 6 months for 3 (3.3%) eyes and 1 month for 2 (2.2%)

eyes. It is possible that one of the eyes currently lost to follow-up has developed ectasia. The 3 eyes with 6-month follow-up had not shown any signs of ectasia on topography at that time point, and sphere and cylinder were stable within 0.25 D. We are continuing to monitor this population and intend to report the stability with longer follow-up.

The reported literature regarding the consequences of performing corneal excimer laser refractive surgery on eyes with keratoconus is confusing. Cases are reported where ectatic progression occurred,¹⁻¹³ and others report it did not occur.^{10,13,34} Buzard et al¹³ reported the results of LASIK in 16 eyes with mild to moderate keratoconus with 1-year follow-up data reported for 11 eyes and 2-year data reported for 5 eyes; UCVA and BSCVA were relatively stable for 13 of 16 eyes at 1 year, but there was ectatic progression in 3 eyes, which required penetrating keratoplasty. Randleman et al¹⁰ reported no ectasia at 1 year for 6 eyes with preoperative topographic evidence of subclinical keratoconus as part of a larger population otherwise consisting of normal eyes. Jampaulo and Maloney³⁴ reported a case of a 40-year-old patient with a preoperative pellucid-type “crab-claw” topographic pattern,

in whom there was no evidence of ectatic progression 7 years after LASIK to treat $-7.25 -3.25 \times 126$ refraction. Cennamo et al³⁵ also reported no progression to ectasia in 25 keratoconic eyes 2 years after topography-guided PRK. Two possible explanations, which may not be mutually exclusive, may account for reports such as these. The cases for which there was no ectatic progression may have been misdiagnosed and may not have actually been keratoconic and/or only some eyes with keratoconus may show ectatic progression following LASIK. We previously demonstrated that a diagnosis of keratoconus can be excluded in some cases with suspicious topography by using an epithelial thickness profile to rule out the presence of an underlying cone.^{17,18} In the present study, we show that by using epithelial thickness profiles, a diagnosis of keratoconus could be excluded in as many as 84% of eyes with suspicious topography. Therefore, it is possible that keratoconus had been misdiagnosed in some of the previously reported cases of LASIK in eyes with apparent mild keratoconus where there was no ectatic progression. Indeed, Buzard et al¹³ state the possibility that some eyes in their study might not have been keratoconic because they had been selected specifically as early cases, with the diagnosis based primarily on topographic findings.

On the other hand, the actual pathophysiological mechanism of ectasia in keratoconus is unknown, and numerous variables might influence the onset of ectasia in a keratoconic eye including age, corneal thickness, residual stromal bed thickness, flap thickness and diameter, ablation depth, relative strength of the anterior and posterior stroma, intraocular pressure, and other biomechanical parameters such as eye rubbing. Although it is now widely accepted that preoperative keratoconus is a risk factor for developing ectasia,¹⁻¹³ it seems plausible that performing LASIK on an eye with keratoconus may not lead to ectasia in 100% of cases. Putting this into the context of the present study, the possibility exists that some eyes actually did have keratoconus but did not progress due to a currently unknown reason.

This study has not provided a definitive answer as to whether screening for keratoconus using epithelial thickness profiles is a reliable method; instead this is a preliminary report in which we demonstrated that operating on eyes with a questionable diagnosis of keratoconus has not led to cases of ectasia as might be expected within 1 year. Although further study will be necessary to determine the exact utility of epithelial thickness mapping in keratoconus screening, it appears that using epithelial thickness profiles may increase the sensitivity and specificity of screening for

keratoconus compared with corneal topography alone and may in fact be useful in clinical practice in two very important ways. First, patients could be excluded from having corneal refractive surgery by detecting keratoconus earlier or confirming keratoconus in cases where we may have considered topographic changes to be "within normal limits." Excluding early keratoconic patients from corneal refractive surgery will reduce and potentially eliminate the risk of ectasia and therefore increase the safety of corneal refractive surgery. Second, epithelial thickness profiles may be useful in excluding a diagnosis of keratoconus despite suspect topography. Epithelial thickening and/or a lack of localized thinning over an area of topographic steepening imply that the steepening is not due to an underlying ectatic stromal surface. In such cases, excluding keratoconus could allow patients to be deemed suitable for corneal laser refractive surgery who otherwise would have been denied treatment.

AUTHOR CONTRIBUTIONS

Study concept and design (D.Z.R., T.J.A., M.G.); data collection (T.J.A., M.G.); interpretation and analysis of data (D.Z.R., T.J.A., M.G.); drafting of the manuscript (D.Z.R., T.J.A., M.G.); critical revision of the manuscript (D.Z.R., T.J.A., M.G.); statistical expertise (D.Z.R., T.J.A.)

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