Functional vision and corneal changes after laser in situ keratomileusis determined by contrast sensitivity, glare testing, and corneal topography

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ABSTRACT

Purpose: To demonstrate the functional vision and corneal changes following laser in situ keratomileusis (LASIK) determined by contrast sensitivity, glare testing, and corneal topography.

Setting: University of Texas Medical School, Houston, Texas, USA.

Methods: Seven patients ranging in age from 20 to 61 years who had bilateral LASIK were evaluated preoperatively and 1 day, 1 week, and 1 and 6 months postoperatively. Visual acuity, using letters on the Baylor Visual Acuity Testor (BVAT) at 98% (standard acuity) and 13% contrast, and the contrast threshold were determined at 3 light levels (darkness, medium brightness acuity testor [BAT], high BAT). Pupil sizes were measured at each level, and corneal topography was performed at each visit.

Results: The greatest changes were found 1 day postoperatively: The contrast threshold worsened by a mean of 0.6 lines ± 1.0 (SD) (P = .05) in darkness, 0.4 ± 0.7 lines (P = .05) at medium BAT, and 0.8 ± 0.7 lines (P = .002) at high BAT. The 98% contrast acuity decreased a mean of 1.4 ± 1.6 lines (P = .01) in darkness, 1.0 ± 2.0 lines (P = .09) at medium BAT, and 0.8 ± 2.3 lines (P = .22) at high BAT. The 13% contrast acuity decreased a mean of 2.2 ± 2.6 lines (P = .01) in darkness, 1.3 ± 1.9 lines (P = .02) at medium BAT, and 1.4 ± 2.5 lines (P = .07) at high BAT. The predicted corneal acuity (PCA) obtained from corneal topography decreased by a mean of 3.3 ± 3.1 lines (P = .002), and the asphericity (Q-value) increased by an average of +0.35 ± 0.67 (P = .07). All values returned to the preoperative levels by 1 week except PCA, asphericity, visual acuity at 13%, and contrast threshold in darkness, which improved slightly but had not returned to baseline by 6 months. The 98% contrast acuity at medium BAT improved by 0.2 ± 1.0 lines (P = .34) and 0.3 ± 0.8 lines (P = .16) at high BAT at 1 month. The 98% contrast acuity values remained 0.3 lines over baseline through 6 months. Corneal topography showed that all corneas became oblate after LASIK to a mean Q-value of +0.47 ± 0.40 (P < .0001) and PCA was decreased by 1.6 ± 1.1 lines (P = .0002) at 6 months.

Conclusions: Functional vision changes do occur after LASIK. The optical quality of the cornea is reduced and the asphericity becomes oblate. Changes in functional vision worsen as the target contrast diminishes and the pupil size increases. These findings indicate that the oblate shape of the cornea following LASIK is the predominant factor in the functional vision decrease. *J Cataract Refract Surg 1999; 25:663–669 © 1999 ASCRS and ESCRS*

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Laser in situ keratomileusis (LASIK) is frequently performed to reduce or eliminate myopic refractive error. Although standard visual acuity testing is an excellent measure of 1 aspect of visual function, contrast sensitivity and glare testing provide much more information.[1–6] We have measured these functional vision parameters in a group of LASIK patients.

The optical quality of the cornea is defined as the quality of the image formed by the cornea as an optical element. The 2 major parameters affecting the optical quality are the surface regularity (microirregularities) and shape (asphericity) of the cornea. Corneal topography is an excellent tool for measuring optical quality changes in the front surface of the cornea, which is the predominant refractive element. We compared the functional vision changes that occurred following LASIK with the preoperative values and correlated them with the optical quality changes in the cornea.

Patients and Methods

The study consisted of 14 eyes in 7 patients who were having bilateral LASIK. The mean age of the patients was 44.4 years ± 12.2 (SD) (range 20 to 61 years). The mean spherical equivalent refractive error was −5.83 ± 2.7 diopters (D) (range −2.25 to −10.12 D). All LASIK procedures were performed using the VISX Star excimer laser system with software version 1.51 (frequency 6 Hz, optical zone 6 mm broad beam) and the Chiron Automated Corneal Shaper microkeratome. Testing was performed preoperatively and 1 day, 1 week, and 1 and 6 months after surgery. The Baylor Visual Acuity Testor (BVAT, Mentor O & O), was used for all functional vision measurements and calibrated to ensure the proper visual angle. The background illumination for the letters on the screen was adjusted to the proper 85 candles/meter^2.

The first step at each visit was to obtain corneal topography using the EyeSys System 2000 (EyeSys Premier) to determine the predicted corneal acuity (PCA)[7,8] and corneal asphericity (Q-value).[8,9] The PCA is calculated over the central 3.0 mm and the corneal asphericity over the central 4.5 mm of the videokeratographic map. The refraction providing the best spectacle-corrected visual acuity (BSCVA) was determined. All subsequent vision measurements at that visit used this refraction. Patients were then taken to a special examining room and allowed to dark adapt for at least 5 minutes. The second step was to determine the contrast threshold by reducing the contrast of randomly presented 20/200 letters until they could not be recognized. In the third and fourth steps, 13% and 98% contrast Snellen letters, respectively, were presented at progressively smaller LogMAR sizes until no letters could be recognized. The second through fourth steps were performed on both eyes and then repeated with normal room illumination (24 foot-candles) and the Brightness Acuity Testor (BAT, Marco Ophthalmic Inc.) on medium and high. The patient was given time to light adapt for several minutes at both medium and high BAT until he or she was comfortable and the vision stable. Pupil diameters were measured at each light level (darkness, medium BAT, and high BAT). For pupil measurement in darkness, a cobalt-blue penlight temporal to the eye was used to avoid direct light in the patient's eye.

Visual acuity results in each patient were recorded and averaged for the study group using previously described methods.[10,11] All P-values were calculated using the Student t test for paired data with different variances. Statistical differences between any functional vision parameters and baseline topographies were determined using statistics in which both eyes of each patient were used.[12–14] Statistical differences were considered significant when $P < .05$.

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Results

Table 1 summarizes the functional vision data at the

Table 1. Preoperative visual parameters (N = 14).*

Parameter	Light Condition: Darkness	Medium BAT	High BAT
Pupil size (mm)	4.8 ± 0.8	3.1 ± 0.5	2.7 ± 0.6
Visual acuity (lines)			
At 98%	20/19 ± 0.7	20/19 ± 0.7	20/19 ± 0.8
At 13%	20/36 ± 1.2	20/34 ± 1.0	20/35 ± 1.1
Contrast threshold (lines)	1.9% ± 0.5	1.6% ± 0.3	1.6% ± 0.4

*All values are mean ± standard deviation preoperative visit. The mean PCA was 20/11 ± 0.4 lines and the mean asphericity, −0.16 ± 0.12. Tables 2 and 3 summarize the same functional vision data at 1 day and 6 months, respectively.

Figure 1 illustrates the change in 98% contrast visual acuity from baseline at each visit at the 3 light levels. Because of only 14 eyes in the study, the power of the statistical tests is very low and requires large differences to be statistically different at a P-value of < .05. The only statistically significant difference occurred on the first postoperative day in darkness when there was a 1.4 line drop in BSCVA.

Figure 2 illustrates the change in 13% contrast visual acuity from baseline. At 1 day, the BSCVA decreased by 1.4 to 2.2 lines at all 3 light levels. At 1 week, the only decrease was in darkness. At 6 months, the BSCVA decrease in darkness was 0.9 ± 0.9 lines (P = .005).

Figure 3 illustrates the change in contrast threshold from baseline at each visit. At 1 day, the contrast threshold was worse at all 3 light levels. By 1 week, medium and high BAT contrast threshold values had not returned to normal, but the differences were not statistically significant. In darkness, however, the values remained approximately 1.0 acuity line worse from 1 week to 6 months.

Figure 4 illustrates the change in PCA from baseline shown by corneal topography. The largest decrease was at 1 day postoperatively. The PCA gradually improved over 6 months, but the decrease at all postoperative visits was statistically significant.

Figure 5 illustrates the mean corneal asphericity obtained by corneal topography. Preoperatively, the asphericity was prolate with a Q-value of −0.16 ± 0.12, which is close to the normal value of previous studies

Table 2. Visual parameters at day 1 (N = 14).*

Parameter	Light Condition		
	Darkness	Medium BAT	High BAT
Pupil size (mm)	5.0 ± 0.5	3.1 ± 0.6	2.4 ± 0.3
Visual acuity (lines)			
At 98%	20/26 ± 1.9	20/24 ± 1.9	20/23 ± 2.2
At 13%	20/60 ± 2.4	20/46 ± 1.7	20/48 ± 2.1
Contrast threshold (lines)	2.9% ± 1.0	2.2% ± 0.6	2.7% ± 0.6

*All values are mean ± standard deviation

Table 3. Visual parameters at 6 months (N = 14).*

Parameter	Light Condition		
	Darkness	Medium BAT	High BAT
Pupil size (mm)	5.7 ± 0.9	2.9 ± 0.7	2.5 ± 0.5
Visual acuity (lines)			
At 98%	20/20 ± 0.6	20/18 ± 0.6	20/18 ± 0.6
At 13%	20/44 ± 1.3	20/35 ± 1.0	20/38 ± 1.0
Contrast threshold (lines)	2.3% ± 0.5	1.6% ± 0.5	1.6% ± 0.3

*All values are mean ± standard deviation

(−0.26). All corneas became oblate (+Q-value) after myopic LASIK. The value reached a maximum by 1 month and then decreased slightly by month 6. All the values were statistically significant.

Discussion

Functional vision changes following LASIK appear to be more significant with lower target contrast and darker testing conditions. These changes would be expected from 1 of 2 causes: (1) microsurface irregularities have been induced or (2) Seidel aberrations (spherical aberration, coma, astigmatism, Petzval curvature, and distortion) have been induced by oblate shape changes in the cornea. If the microirregularities are fairly uniform over the 6 mm optical zone, the reduction in contrast sensitivity is almost independent of pupil size and light level. Shape changes causing spherical, coma, and astigmatic aberrations from an oblate shape will be directly related to pupil size and will worsen as light levels decrease.[15] These relationships have been described in a study of patients having radial keratotomy.[16]

Our data indicate that high-contrast (98%) standard acuity returned to preoperative levels within 1 week. At medium and high BAT, with smaller pupils, the acuities actually exceeded preoperative levels by 0.3 line at 1 month. This improvement would be expected from the reduction in minification from the mean preoperative spectacles of −5.83 D. With large pupils in darkness, the fact that the acuities were slightly less than preoperative values after 1 month suggests that the optical quality of the cornea reduces visual function slightly more than the improvement from reduced minification. Since this optical quality change is dependent on pupil size, it indicates that this is due to a shape change in the

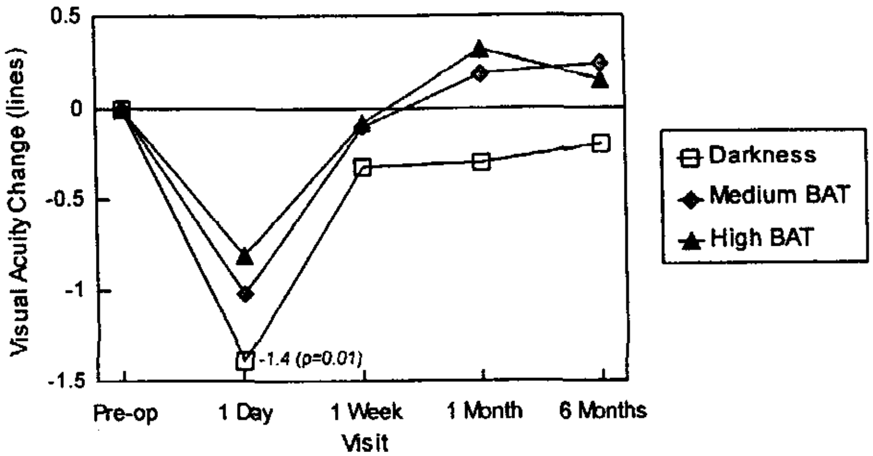

Figure 1. (Holladay) The change in 98% contrast visual acuity from baseline at each visit at the 3 light levels. The greatest changes occurred at 1 day. At 6 months, the visual acuity in darkness decreased by 0.2 ± 0.7 line (P = .35), and the medium and high BAT levels exceeded baseline slightly (+0.2 ± 0.6 line [P = .40]).

cornea from prolate to oblate (i.e., a change in asphericity) in contrast to microirregularities, which would not be pupil-size dependent.

Although the change in optical quality of the cornea as measured by PCA was reduced by 1.6 lines at 6 months, the preoperative mean PCA was 20/11. A reduction of 1.6 lines would result in an average acuity of 20/16. Since the average normal visual acuity (combined group, N = 66) is 20/17, the reduction in the PCA is not the limiting factor in BSCVA. Therefore, the microscopic irregularity does not affect visual performance clinically.

These observations are confirmed by the 13% contrast data. At medium and high BAT, the values almost returned to baseline between 1 week and 1 month and then remained stable. The fact that the values in darkness did not return to baseline by 6 months indicates that optical quality changes in the cornea are pupil-size dependent. Therefore, the predominant factor in the reduction of visual function with larger pupils is the change in corneal asphericity to oblate (+Q-value).

Our data indicate that the contrast threshold is not stable in all light levels by 6 months and is worse in darkness in eyes with large pupils. Since contrast thresh-

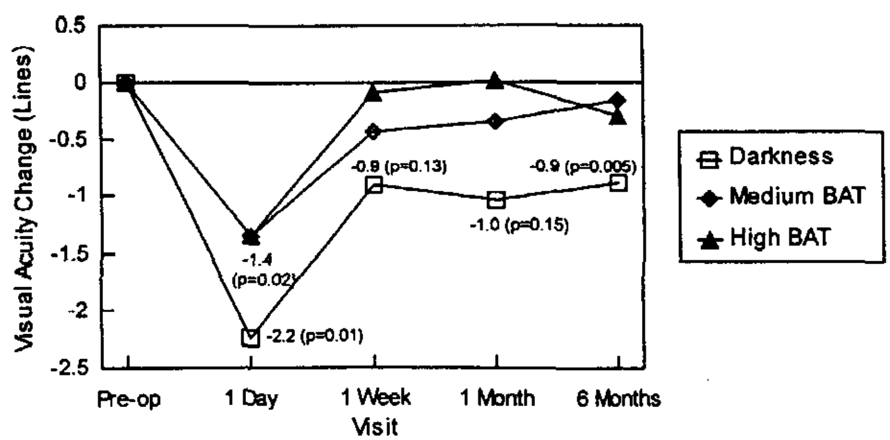

Figure 2. (Holladay) The change in 13% contrast visual acuity at each visit at the 3 light levels. The greatest changes occurred at 1 day. The acuity appeared to stabilize by 1 week. At 6 months, the visual acuity in darkness was decreased by 0.9 ± 0.9 line (P = .005), and at medium and high BAT, it was slightly less than baseline (−0.2 ± 0.8 line [P = .54]) and −0.3 ± 1.4 lines [P = .44], respectively).

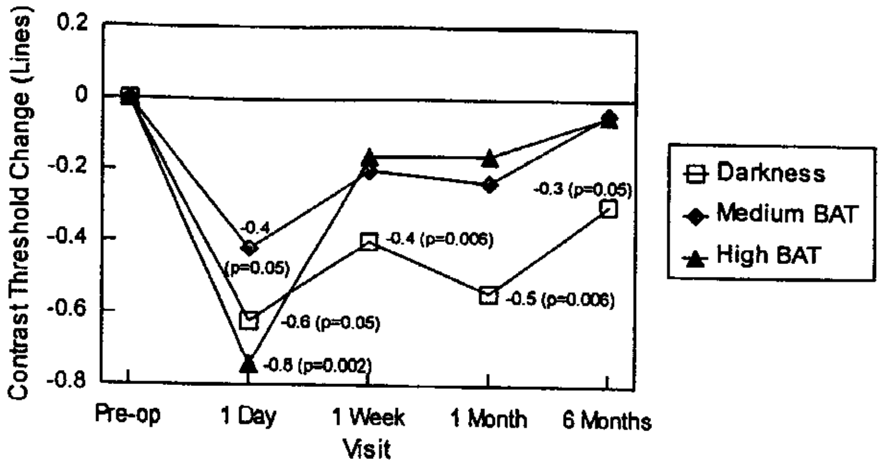

Figure 3. (Holladay) The change in contrast threshold from baseline at each visit at the 3 light levels. The greatest changes occurred at 1 day. The visual acuity improved progressively for 6 months; at medium and high BAT it approached baseline (−0.1 ± 0.4 line [P = .65]), but in darkness it was decreased by 0.3 ± 0.6 line (P = .05).

old in darkness is the most sensitive measure of functional vision,[17] this value would be expected to take the longest to return to normal. It is not known whether this value returns to normal after 6 months, but since the change is likely because of permanent aspheric changes in the cornea, it is unlikely.

Conclusion

Functional vision changes do occur following LASIK. They are due to changes in the optical quality of the cornea. Optical quality changes can be due to microirregularities that are predicted by the PCA or by shape (aspheric) changes in the cornea as reflected by the Q-values. Our findings indicate that in normal individuals, the optical quality of the cornea due to microirregularities (20/12) is 1.2 lines better than the mean measured visual acuity (20/17). Therefore, the retina or crystalline lens must be the limiting factor in visual performance. In short, if the cornea is capable of resolving 20/12 letters but the retina or crystalline lens is capable of only 20/17, the measured acuity is 20/17. After 1 month, it is unlikely that microirregularities in the cornea following LASIK have a significant impact on visual function.

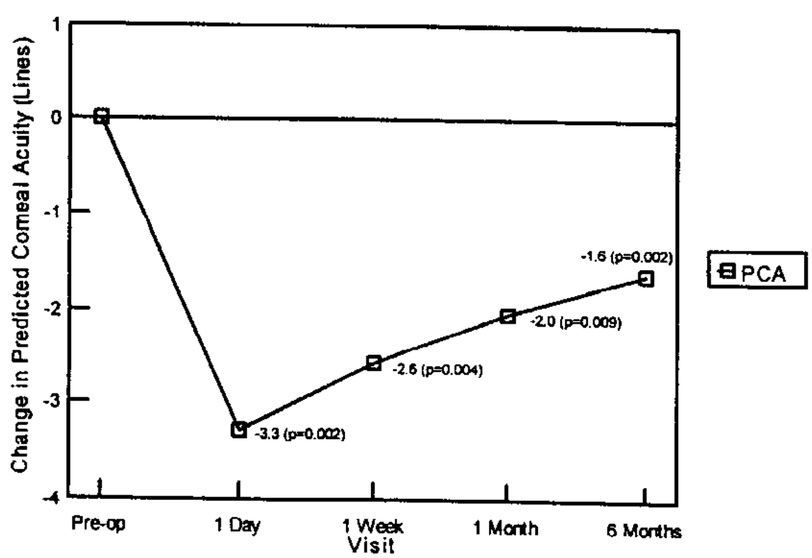

Figure 4. (Holladay) The change in PCA from baseline obtained by corneal topography. The mean decrease was 3.3 ± 3 lines (P = .002) at 1 day. At 6 months, the PCA decreased by 1.6 ± 1.1 lines (P = .0002) and had not stabilized.

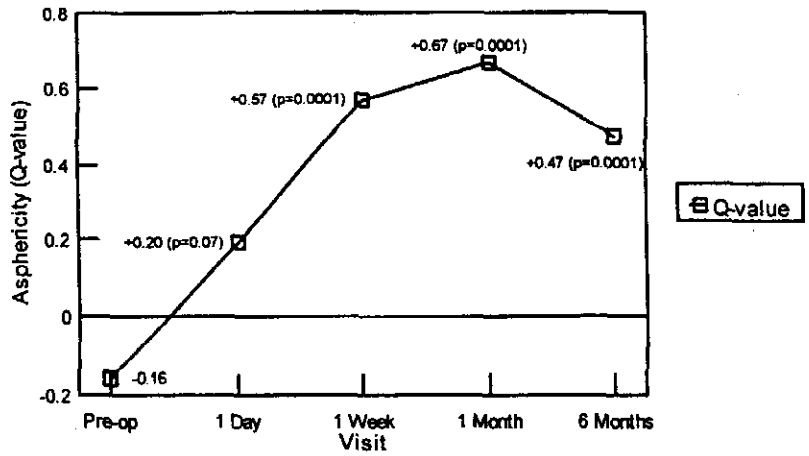

Figure 5. (Holladay) The mean corneal asphericity obtained by corneal topography. The mean preoperative asphericity was prolate (Q-value = −0.16 ± 0.12) and changed to oblate at all subsequent visits. The maximum Q-value was +0.67 ± 0.41 ($P < .0001$) at 1 month; the value was +0.47 ± 0.40 ($P < .0001$) at 6 months and had not stabilized.

However, since none of the visual function parameters measured in darkness returned to normal, the aspheric change in the cornea is the predominant factor in limiting visual performance. The lower the contrast of the object and the larger the pupil, the more significant the reduction in visual performance.

Whether a permanent 0.3 line decrease in contrast threshold is clinically significant is difficult to determine. For some tasks in conditions of reduced contrast and low light levels (driving a car or flying a plane at night) or occupations such as military and law enforcement, visual function changes induced by LASIK may be important. Recognizing that the reductions in visual performance are due to a change in asphericity suggests that efforts to maintain the normal prolate corneal asphericity following LASIK may be important. Future developments in excimer laser technology must include changes in the profile algorithm to maintain the normal prolate corneal asphericity after ablation.

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