Effect of lamellar flap location on corneal topography after laser in situ keratomileusis

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ABSTRACT

Purpose: To investigate the effect of hinge position on corneal topography after laser in situ keratomileusis (LASIK) for myopia.

Setting: Academic center and refractive surgery practice.

Methods: Topography data obtained from 89 eyes of 46 patients after LASIK were analyzed. Using a system of Cartesian coordinates, data along the horizontal and vertical axes were analyzed, measuring sagittal height and power change at 1 mm intervals from the ablation zone center. Data points that were equidistant and on opposite sides of the ablation center were compared to find asymmetry along either axis relative to nasally hinged flaps.

Results: Along the horizontal axis, areas of the cornea closer to the hinge had a higher topography than areas farther from the hinge. Specifically, the points nearest and farthest from the hinge were significantly different in sagittal height ($P < .034$); the areas farthest from the hinge were reduced more after surgery (relatively lower topography). When results were stratified into low- and high-diopter corrections, this difference was significant in only the high-diopter group ($P < .0006$). Trends in power change were also observed. Areas of the cornea closer to the hinge were relatively flatter than areas farther from the hinge. Statistical significance was detected in only the low-diopter group at data points 2 mm from the ablation zone center in opposite directions ($P < .008$). No asymmetry was seen along the vertical axis in power change or sagittal height.

Conclusions: The lamellar flap in LASIK may influence postoperative corneal topography. Hypothetically, the corneal flap may retract toward the hinge, producing axial asymmetry in the postoperative topography relative to the hinge. Understanding the influence of corneal flap characteristics on post-LASIK topography may improve optical results and may be particularly important in the development and effectiveness of topography-guided ablation techniques. J Cataract Refract Surg 2000; 26: 992–1000 © 2000 ASCRS and ESCRS

Laser in situ keratomileusis (LASIK) involves raising a lamellar corneal flap attached to the eye by a hinge of corneal tissue and removing midstromal tissue by excimer laser photoablation. The topographic changes in the corneal surface after excimer laser surgery have been well studied. Although these studies have elucidated optical outcomes after refractive surgery, none has looked specifically at the effect of lamellar hinge placement on corneal topography after LASIK. In this study, we isolated and studied changes in postoperative corneal topography that resulted from the hinge location.
Patients and Methods

Laser In Situ Keratomileusis Procedure

The corneal topography of 89 eyes of 46 patients who had LASIK to correct myopia was investigated. The mean patient age was 38.50 years ± 8.76 (SD) (range 22 to 57 years).

One surgeon (P.S.H.) performed all laser procedures using the Apex Plus® excimer laser system (Summit Technology). In all eyes, the procedure was centered over the entrance pupil, with the patient fixating coaxially. To ensure appropriate laser energy and beam homogeneity, ablation and beam profile characteristics were tested at the beginning of each treatment day, as described.² Laser parameters included a repetition rate of 10 Hz, radiant exposure of 180 mJ/cm² at the corneal plane, and pulse duration of 14 nanoseconds, resulting in a stromal tissue ablation rate of approximately 0.25 μm per pulse. The beam diameter was 6.0 mm in all cases. During the procedure, the Automated Corneal Shaper microkeratome (Chiron Vision Inc.) with the LASKI ring was used to prepare a corneal flap approximately 8.5 mm in diameter and nominally 160 or 180 μm thick. The hinge was placed nasally in all eyes. The flap was positioned to the side and laser ablation performed. Filtered balanced salt solution was placed on the flap and stromal bed, and the corneal flap was repositioned. Approximately 3 to 5 minutes were allowed to ensure proper adherence of the flap.

Analysis of Corneal Topography

Corneal topography measurements were made preoperatively and, on average, 51 days postoperatively. Topography data were acquired by a trained technician using the PAR Corneal Topography System, software version 2.1 (PAR Vision Systems Corp.), which displays sagittal height and radius of curvature based on the principle of rasterstereography.¹¹ Rasterstereography was selected over videokeratoscopy because unlike Placido disk systems, it more directly measures sagittal height. In addition, rasterstereography units have been shown to represent surface topographic elevations and depressions more accurately.¹²

One investigator (N.E.G.) performed subsequent data analysis. The quantitative changes in corneal topography produced by the LASIK procedure were determined by reviewing the differential topography map, derived by subtracting the preoperative from the postoperative map, for power and sagittal height. The differential map was used instead of the postoperative map because it best reflects the changes in corneal contour ascribed to laser treatment, hinge location, and wound healing.

A transparent grid with a Cartesian coordinate system was placed over each differential map so the center of the grid was superimposed on the center of the ablation zone. The dioptric change and sagittal height change (measured in millimeters) were noted with the help of the computer cursor and the legend on the topography map, which indicated the distance to the nearest 0.01 mm and the angle (θ, in meridian degrees) of the position of the computer cursor from the center of the grid. Two differential maps were used, 1 looking at the corneal refractive power change (measured to the nearest 0.001 diopter [Δ]) and the other at corneal sagittal height change (measured to the nearest 0.001 mm). Using the Cartesian coordinates, the cursor was placed on specific points and the legend displayed the value for that point, either power or sagittal height, with corresponding distance to the center and meridian. Corneal topographic measurements for power and sagittal height changes were obtained for positions at the center of the grid and 1, 2, and 3 mm from the center in all cardinal directions (0, 90, 180, and 270 degrees). Data points farther than 3 mm from the center of the treatment zone were not obtained because they were beyond the area measurable by the PAR topography unit.

Data were entered into an Excel database (Microsoft) and mean power change ± standard deviation and mean sagittal height change ± standard deviation were computed in all 4 directions at all distances measured. Data were arranged and pooled for both eyes, so the values corresponded both to the distance from the ablation center and relative position to the hinge; i.e., whether closer to or farther from the hinge. Asymmetry along each axis was detected by comparing data points that were equidistant from the ablation center but on opposite sides with respect to the hinge. For example, along the horizontal axis, points 3 mm from the ablation center toward the hinge were compared to points 3 mm from the ablation center away from the hinge (Figure 1, top); this was repeated for points 2 mm and 1 mm from the ablation center.
Vertical data were arranged and pooled similarly so values corresponded to the distance from the ablation center. Points 3 mm from the ablation center in the 90 degree meridian were compared to points 3 mm from the ablation center in the 270 degree meridian and similarly for points 2 mm and 1 mm from the ablation center. This method of comparison allowed determination of asymmetry along the vertical axis for power or sagittal height.

Further analysis was accomplished by stratifying the data according to attempted correction. Cutoff values were $>6.0$ D (sphere) for high-diopter attempted corrections and $\leq 6.0$ D for low-diopter attempted corrections. Determining statistically significant differences between matched data points was accomplished using a homoscedastic Student $t$ test. A $P$ value of $<.05$ was considered significant.

Control for Ablation Profile

To verify that the results were related to flap hinge location and not systematically due to beam fluence nonhomogeneity or other laser- or ablation-related effects, a series of comparative statistical tests was used. Data from all eyes were pooled, and points were compared regardless of their relationship to the hinge but relative to the orientation of the ablation zone (Figure 1, bottom). In other words, at each millimeter point, the temporal data from the right eye were pooled with the nasal data from the left eye; these were compared to the pooled data for the nasal region of the right eye.
eye and the temporal region of the left eye. The points were compared to their mirror image on the ablation zone to look for systematic ablation zone topography irregularities.

**Results**

The mean attempted correction in the 89 eyes was $-6.90 \pm 2.93$ D (range $-2.90$ to $-12.00$ D) and the mean cylinder, $-0.95 \pm 0.86$ D.

The mean time between preoperative and postoperative topographic maps was 51 days.

Comparison of data relative to the orientation of the beam ablation zone, regardless of the relationship to the hinge, showed no statistical significance between points from opposing sides for any parameter (power or sagittal height change) along the horizontal or vertical axis (Figure 1, bottom).

**Overall Changes in Corneal Topography**

Mean power and sagittal height changes in all eyes are shown in Table 1 and Figure 2. Values are arranged by increasing distance from the center of the ablation zone. Along the horizontal axis, negative distances ($-1, -2, -3$ mm) indicate data points increasing in distance from the ablation center toward the hinge and positive distances ($+1, +2, +3$ mm), data points increasing in distance from the ablation center away from the hinge. Along the vertical axis, positive distances indicate values that are superior to the ablation center, while negative distances indicate values that are inferior to the ablation center.

Table 1 and Figure 2, top, show a slight trend in relative flattening of the area of the cornea closest to the hinge (greater power change). The area farthest from the hinge shows more sagittal height change or lowering (Figure 2, bottom).

Comparing the relative position of all data points to the hinge showed a statistically significant difference in sagittal height in the horizontal axis between points 3 mm from the ablation center toward the hinge and 3 mm from the ablation center away from the hinge; the mean sagittal height change closer to the hinge ($-0.011 \pm 0.007$ mm) was less than the mean sagittal height change farther from the hinge ($-0.013 \pm 0.007$ mm) ($P < .034$). The postoperative sagittal height of the section of the area near the hinge was higher than that of the area away from the hinge. This difference was more apparent following stratification of the data into high and low attempted correction. No other data points in the pooled group were statistically significant for power or sagittal height changes in the horizontal or vertical axis.

**Stratification into High- and Low-Diopter Corrections**

The high-diopter cohort consisted of 40 eyes with a mean attempted correction of $-9.54 \pm 2.10$ D and the low-diopter cohort, of 49 eyes with a mean attempted correction of $-4.67 \pm 1.16$ D. Tables 2A and 2B and Figure 3 show the mean power and sagittal height changes in both groups. In the low-diopter group, there was a statistically significant difference between 2 power change data points on the horizontal axis. The mean power change in points 2 mm away from the ablation zone in opposite directions was significantly different. The area closer to the hinge was relatively flatter (power change $-4.177 \pm 1.54$ D) than the area farther from

<table>
<thead>
<tr>
<th>Table 1. Mean power and sagittal height change in all eyes.</th>
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<tr>
<td><strong>Distance from Center of Ablation Zone</strong></td>
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*Bold values are statistically significant data points ($P < .034$).
the hinge (power change $-3.496 \pm 1.46$ D) $(P < .008)$. No other points in the low-diopter group were statistically significant.

In the high-diopter group, as in the pooled analysis, the points 3 mm from the ablation zone in opposite directions were significantly different in sagittal height change $(P < .0006)$. Again, the area closer to the hinge was relatively higher than that farther from the hinge (Table 2A and Figure 3, bottom). All other values were statistically insignificant. No values on the vertical axis

<table>
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<tr>
<th>Table 2A. Mean power and sagittal height change in high-diopter (&gt;6.0 D) group.</th>
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<tr>
<td><strong>Axis</strong></td>
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<tr>
<td>Vertical</td>
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<tr>
<td>Mean power change (D)</td>
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<td>Mean sagittal height change (mm)</td>
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*Bold values are statistically significant data points $(P < .0006)$. 
were statistically significant in power change or sagittal height in either group.

The 2 groups were not stratified by flap thickness nor was intraoperative pachymetry performed. No attempt was made to conclude whether flap thickness contributed to the findings.

Table 2B.  Mean power and sagittal height change in low-diopter (≤6.0 D) group.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Distance from Center of Ablation Zone</th>
<th>Mean power change (D)</th>
<th>Mean sagittal height change (mm)</th>
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<tr>
<td></td>
<td>−3 mm</td>
<td>−2 mm</td>
<td>−1 mm</td>
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<td>Horizontal</td>
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<tr>
<td>Mean power change (D)</td>
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<td>Mean sagittal height change (mm)</td>
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<td>−0.036</td>
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<td>Vertical</td>
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<tr>
<td>Mean sagittal height change (mm)</td>
<td>−0.004</td>
<td>−0.036</td>
<td>−0.054</td>
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*Bold values are statistically significant data points (P < .008).

Figure 3. (Ginsberg) Top: Mean power change for data stratified by attempted correction; horizontal axis. The x-axis shows distance from the center of the ablation zone. Negative distances (−1, −2, −3 mm) indicate data points increasing in distance from the ablation center toward the hinge. Positive distances (+1, +2, +3 mm) indicate data points increasing in distance from the ablation center away from the hinge. Note the trend of greater power change (relative flattening) in areas closest to the hinge. Bottom: Mean sagittal height change for data stratified by attempted correction; horizontal axis. Note the trend of greater sagittal height change (relative lowering) in areas farthest from the hinge. Left: Mean power change for data stratified by attempted correction; vertical axis. The x-axis shows distance from the center of the ablation zone. Positive distances indicate values that are superior to the ablation center and negative distances, values that are inferior to the ablation center. Right: Mean sagittal height change for data stratified by attempted correction; vertical axis.
Discussion

The goal of any refractive surgical procedure is creation of a corneal surface that optimizes visual acuity and other objective measurements of overall visual function while minimizing optical aberrations. Thus, an understanding of the optical topography of the cornea following LASIK is essential to explain the objective and subjective clinical results and improve the overall visual outcome of the procedure. In addition, with the development of topography-guided ablation, information about the topographic influence of the lamellar flap will be important.

In this study, we analyzed 2 specific measures of corneal topography—corneal power change and sagittal height change. Both measures are necessary since a change in corneal shape may result from both elevation and depression of the flap. For instance, one area may be relatively higher and steeper, whereas another might be relatively lower but still have the same contour as the higher area. With both parameters in mind, we wanted to know whether there was a meridional difference in these measures relative to the lamellar hinge.

Our results showed that on the vertical axis there was generally no significant difference in power or sagittal height. On the horizontal axis, the area of the cornea closest to the hinge showed more flattening (more power change) and less sagittal height change (relatively higher). Areas farthest from the hinge on the horizontal axis were relatively steeper and had a greater sagittal height change (relatively lower). These findings suggest that the lamellar corneal flap may play a role in corneal topography after LASIK.

The vertical axis showed no significant difference between points opposite the center of ablation. This is expected since asymmetric effects of hinge placement should be predominantly in the axis of the hinge. Flap-associated changes in the vertical axis would be symmetrical and, thus, not detected by our study methodology.

Possible Causes of Topographic Changes

We postulate that retracting the lamellar flap toward the hinge may produce the findings we have demonstrated. Flap retraction was proposed in a previous study.8 In this theory, the hinge in its nasal position acts as an anchor to which vectors of retraction are directed.

As the temporal portion of the corneal flap retracts nasally (noted clinically as the “gutter” around the flap), its curvature steepens relatively (Figure 4). This would cause a decrease in overall power change (less relative correction) on the differential map compared to the power change expected if there were no flap retraction. These same forces may cause the increase in sagittal height change at the temporal region found in our study. The converse is true for the hinged region of the cornea. Near the hinge, where the flap is fixed nasally and posteriorly, the cornea flattens and its...
sagittal height changes less than on the temporal side. This mechanism also suggests a generalized relative steepening in the vertical axis (induced against-the-rule astigmatism); this was not detectable in our study, however.

Our finding of a meridional orientation of power and sagittal height changes corroborates findings of previous studies. A prior study by our group showed that astigmatism was generally less in LASIK than in photorefractive keratectomy (PRK). We theorized that the lamellar corneal flap in LASIK may counteract the tendency toward steepening at 90 degrees seen in PRK (induced with-the-rule astigmatism) by retracting toward the hinge, with consequent flattening of the vertical axis. Our results substantiate the theory that decreased astigmatism could be due to flap retraction while still causing the changes in power and sagittal height that we have observed.

Other studies have noted a meridional difference in certain topographic patterns such as keyhole and semi-circular. They report steeper areas projecting inferotemporally in these patterns, with the maximum refractive effect located nasally. The authors suggest that other conditions may be involved in the changing topography, including asymmetries in beam profile. This possibility was addressed in this study, showing that there was no significant difference at any point (power or sagittal height) along any axis when points were compared regardless of their relationship to the hinge but with respect to orientation of the ablation zone. Thus, systematic effects of laser beam profile did not appear to be present.

Another possible cause of aberrant topography is the laser–tissue interaction. This interface can be affected by corneal hydration during the procedure and variations in stromal hydration leading to differential ablation rates across the optical zone. Theoretically, hydration shifts could be meridionally biased based on corneal lamellar architecture or surrounding configuration of the orbit and nose, causing the topographic changes seen. Wound healing, which may explain optical aberrations in PRK, is probably not a cause of the topographic patterns we observed. Studies have shown that corneal healing following LASIK occurs predominantly at the periphery of the microkeratome wound, leaving the central optical zone intact.

Conclusion

Although the clinical implications of these findings are not clear, we present evidence that hinge placement does have an effect on postoperative corneal topography. If true, this theory suggests that altering the hinge placement, changing the thickness of the flap, or changing its shape may affect optical outcomes and topography changes after LASIK. To date, LASIK treatments have generally been based solely on refractive error, without regard to individual patient characteristics. In the future, customized optical algorithms could potentially consider how the lamellar hinge affects corneal topography. Hinge placement may also play a role in the development of topography-guided ablation. Knowledge of the mechanical and optical effects attributable to the flap could one day determine the optimum position, thickness, and shape of the lamellar flap prior to ablation. Further study of the LASIK flap will lead to better methods to achieve an optimum topography after laser refractive surgery.

References

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From the Department of Ophthalmology, UMDNJ–New Jersey Medical School, Newark; Hackensack University Medical Center, Hackensack; The Cornea and Laser Eye Institute, Teaneck, New Jersey, USA.

Supported in part by an unrestricted grant from Research to Prevent Blindness, Inc., New York, New York, USA.

Neither author has a financial interest in any product mentioned.