Time Course of Changes in Corneal Forward Shift After Excimer Laser Photorefractive Keratectomy

Kazunori Miyata, MD; Kazutaka Kamiya, MD; Tetsuya Takahashi, MD; Tatsuro Tanabe, MD; Tadatoshi Tokunaga, COT; Shiro Amano, MD; Tetsuro Oshika, MD

**Background:** Excimer laser refractive surgery has been reported to induce forward shift of the cornea, but its long-term sequelae remain unknown.

**Objectives:** To prospectively investigate the time course of changes in corneal elevation after excimer laser photorefractive keratectomy (PRK).

**Methods:** We performed PRK on 65 eyes of 34 patients with refractive errors of −1.25 to −10.0 diopters. The anterior/posterior corneal elevation and corneal thickness were measured with a scanning-slit corneal topography system before and 1 week and 1, 3, 6, and 12 months after surgery. Twenty eyes of 10 healthy control subjects underwent similar measurements at 3-month intervals.

**Results:** The posterior corneal surface displayed a mean±SD forward shift of 36.6±25.3 µm 1 week after PRK, which gradually increased to 55.1±46.1 µm at 1 year. All postoperative values were significantly larger than those of healthy controls (2.4±8.9 µm; \( P<.001 \), Mann-Whitney test). The largest forward shift occurred within the first postoperative week. The progression thereafter was most pronounced from 1 to 6 months, and nearly stabilized at 6 months. The variance of postoperative data was statistically significant (\( P<.001 \), repeated-measures analysis of variance). Multiple postoperative comparisons demonstrated significant differences between measurements at 1 week and 6 months (\( P=.002 \), Tukey Honestly Significant Difference), at 1 week and 1 year (\( P<.001 \), at 1 and 6 months (\( P<.001 \), and at 1 month and 1 year (\( P<.001 \)). Progression of forward shift was more prominent in eyes with less preoperative corneal thickness and greater myopia that required larger laser ablation. We observed no progressive thinning and expansion of the cornea during the 1-year follow-up, which refuted the occurrence of true ectasia. A statistically significant correlation was found between the amount of myopic regression and the forward shift of the cornea (Pearson correlation coefficient, \( r=-0.37; P=.005 \)).

**Conclusions:** Photorefractive keratectomy induced forward shift of the cornea, which is not true corneal ectasia. The largest forward shift occurred within the first postoperative week. Changes were progressive up to 6 months postoperatively, but became almost stable thereafter. Eyes with thinner cornea and higher myopia, requiring greater photoablation, are more predisposed to progression. Forward shift of both corneal surfaces added to the tendency toward myopic regression after PRK.

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EXCIMER LASER refractive surgery modifies the refractive power of the cornea by means of photoablation of the corneal tissue. There is concern that the cornea is structurally compromised by the surgical tissue subtraction and by the loss of integrity of the Bowman membrane after excimer laser surgery. Several cases of iatrogenic keratectasia after excimer laser surgery have been documented. In a series of patients undergoing laser in situ keratomileusis, forward shift of the posterior corneal surface has been demonstrated, which correlated with the residual corneal bed thickness and the amount of laser ablation. Increases in posterior corneal curvature resulting from forward bulging of the cornea after photorefractive keratectomy (PRK) and laser in situ keratomileusis also have been reported. The long-term course of these changes, however, has not been studied. Considering the expected longevity of patients undergoing refractive surgery, it is critical to investigate whether progressive anterior protrusion of the cornea occurs after refractive surgery. In addition, forward shift of the cornea can cause myopic regression after excimer laser surgery. Thus, longitudinal assessment of the corneal geometric changes in relation to refractive regression after PRK is also important. We conducted a prospective study to evaluate the time course of changes in anteroposterior movement of the cornea after PRK.
Anterior/posterior corneal elevation and corneal thickness were measured with scanning-slit topography (Orbscan; Bausch & Lomb, Rochester, NY) before and 1 week and 1, 3, 6, and 12 months after surgery. Changes in the elevation of the posterior corneal surface were evaluated at the center of the difference map generated from preoperative and postoperative elevation maps. For surface alignment in the difference map, the 3-mm-wide peripheral annular fit zone was used.\(^{11-13}\) Elevation of the anterior corneal surface was assessed in terms of changes from the first postoperative week using the difference map made from the first week and subsequent postoperative maps. The amount of myopic regression was calculated as the change in refraction between 1 week and 1 year after PRK.

Twenty eyes of 10 healthy control subjects (mean age, 30.5 ± 6.2 years) underwent scanning-slit topographic measurements at 3-month intervals. Their refraction was −1.87 ± 0.94 D. They had no ocular disease except mild refractive errors.

### RESULTS

The number of eyes examined at each postoperative visit is listed in Table 1. Data were collected from more than 90% of eyes on each follow-up occasion, and all patients completed at least 4 of 5 predetermined postoperative examination visits. Time course of changes in mean refraction is shown in Figure 1. The surgery reduced the mean manifest spherical equivalent from \(-5.29 ± 1.97\) diopters (D) (range, \(-1.25\) to \(-10.00\) D) eyes with keratoconus were excluded by using the keratoconus screening test of Placido disk videokeratography (TMS-2; Computed Anatomy Inc, New York, NY). Informed consent was obtained from all patients.

Photorefractive keratectomy was performed with an excimer laser system (VISX Twenty-Twenty; VISX, Inc, Santa Clara, Calif) using an average fluency of 160 mJ/cm\(^2\) and a repetition rate of 6 Hz. Ablation depth was \(60.3 ± 23.1\) µm (range, 13-109 µm). In all eyes, we selected the preoperative manifest refraction as the target correction.

### Table 1. Postoperative Data

<table>
<thead>
<tr>
<th>Postoperative Time</th>
<th>1 wk</th>
<th>1 mo</th>
<th>3 mo</th>
<th>6 mo</th>
<th>1 y</th>
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</thead>
<tbody>
<tr>
<td>No. (%) of eyes examined</td>
<td>65 (100)</td>
<td>63 (97)</td>
<td>60 (92)</td>
<td>59 (91)</td>
<td>65 (100)</td>
</tr>
<tr>
<td>Forward shift of posterior corneal surface, µm</td>
<td>(36.6 ± 25.3) (–7 to 111)</td>
<td>(33.8 ± 31.3) (–13 to 123)</td>
<td>(43.5 ± 38.8) (–8 to 165)</td>
<td>(52.7 ± 47.6) (3 to 196)</td>
<td>(55.1 ± 46.1) (–5 to 184)</td>
</tr>
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<td>Forward shift of anterior corneal surface, µm</td>
<td>(35.3 ± 25.3) (–7 to 111)</td>
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<td>(52.7 ± 47.6) (3 to 196)</td>
<td>(55.1 ± 46.1) (–5 to 184)</td>
</tr>
<tr>
<td>Corneal thickness, µm</td>
<td>(458.5 ± 55.8) (327 to 550)</td>
<td>(457.5 ± 58.6) (326 to 552)</td>
<td>(467.9 ± 55.7) (345 to 546)</td>
<td>(475.5 ± 55.1) (349 to 552)</td>
<td>(478.3 ± 52.2) (362 to 562)</td>
</tr>
<tr>
<td>Myopic regression, D</td>
<td>(0.18 ± 0.75) (–1.38 to 2.00)</td>
<td>(0.28 ± 1.10) (–2.00 to 5.00)</td>
<td>(0.48 ± 1.03) (–1.50 to 4.38)</td>
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*Unless otherwise indicated, data are given as mean ± SD (range). D indicates diopters.
changes were symmetric in magnitude and time course throughout the 1-year observation. The variance of anterior corneal shift was statistically significant ($P<.001$, repeated-measures analysis of variance). Multiple postoperative comparisons demonstrated significant differences between measurements at 1 week and 6 months ($P=.002$, Tukey Honestly Significant Difference), at 1 week and 1 year ($P<.001$), at 1 and 6 months ($P<.001$), and at 1 month and 1 year ($P<.001$). Error bars represent SD.

In each eye, a regression line was created for the postoperative posterior corneal elevation from 1 week to 1 year (52 weeks), and the inclination of the line was computed using the least squares method. According to the sign (positive or negative) of the inclination, eyes were divided into the following 2 groups: eyes that showed progressive forward shift of the cornea during the 1-year observation (39 eyes) and those that did not (26 eyes). Clinical data were compared between these groups. As shown in Table 2, preoperative corneas were significantly thinner in the progression than in the nonprogression group ($P=.01$, Mann-Whitney test). Achieved myopic correction was significantly larger in the progression than in

<table>
<thead>
<tr>
<th>Table 2. Comparison of Data According to the Occurrence of Progressive Forward Shift*</th>
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<tbody>
<tr>
<td>Progression</td>
</tr>
<tr>
<td>Age, y</td>
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<tr>
<td>Preoperative intraocular pressure, mm Hg</td>
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<tr>
<td>Preoperative corneal thickness, µm</td>
</tr>
<tr>
<td>Achieved myopic correction, D</td>
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</table>

*Unless otherwise indicated, data are given as mean ± SD. D indicates diopters.
the nonprogression group (P = .01). No intergroup difference in patient age and preoperative intraocular pressure was found.

In the present 1-year prospective study, we found a trend toward progressive forward shift of the posterior corneal surface after PRK. Although the progression tended to stabilize after 6 months, marked postoperative changes were observed between 1 and 6 months (Figure 2). The progressive forward shift, however, did not occur in every case. Among the 63 eyes, 39 (60%) showed a tendency to forward progression and 26 (40%) did not. The cases with forward progression were found to have had significantly thinner preoperative corneas and higher myopia to be corrected. Baek et al., who investigated factors affecting the anteroposterior movement of the cornea 1 month after laser in situ keratomileusis, reported that eyes with thinner corneas and higher myopia requiring greater laser ablation are more predisposed to the anterior shift of the cornea. The present study indicates that less corneal thickness and greater myopic correction are the risk factors for progressive forward movement of the cornea after PRK.

The reproducibility/accuracy of the scanning-slit topography has been discussed in previous articles. The reproducibility of 2 consecutive measurements of spherical power has been reported to be 0.80% in healthy human eyes. In eyes with keratoconus, reproducibility indices were 1.73% and 2.16% for the anterior and posterior surfaces, respectively. These values are comparable with the 0.9% obtained by means of Placido disk videokeratography in healthy controls. Kamiya et al. reported that the instrument has sufficient sensitivity to detect surgically induced changes in posterior corneal curvature. Baek et al. reported that 2 consecutive measurements of the posterior surface elevation in healthy eyes yielded a mean variation of 2.0 ± 1.7 μm, accounting for less than 0.4% of the total corneal thickness. Seitz et al. described that repeating the measurement of posterior corneal power 3 times by the same examiner revealed a reliability coefficient of 0.96 (Cronbach α), indicating a high reproducibility (small test-retest variability). In the present study, we measured 20 healthy eyes at 3-month intervals and obtained a variability of 2.4 ± 8.9 μm for the posterior corneal elevation. High reproducibility may not correlate with high accuracy. However, in studies that deal with time changes, eg, preoperative and postoperative changes, it is not irrelevant to assess reproducibility of the measurements to see the applicability of data. The current and previous results suggest that the scanning-slit topography possesses reasonable accuracy in the comparative assessment of posterior corneal surface.

Because the anterior surface of the cornea after refractive surgery, especially after PRK, is subject to epithelial and stromal wound healing, changes in the anterior corneal elevation may not directly indicate general corneal protrusion. The ability to individually assess the anterior and posterior corneal surfaces may facilitate the better understanding of surgical physiology of the cornea after excimer refractive surgery.

Severe cases of iatrogenic keratectasia have been seen after excimer laser corneal surgery. The term corneal ectasia, however, is not appropriate for the forward shift of the cornea observed in the present study. Progressive thinning of the cornea did not occur during the 1-year postoperative period (Table 1), and forward shift of the anterior corneal surface was highly similar in magnitude and time course to that of the posterior corneal surface (Figure 4). The patients even showed gradual increases in the corneal thickness, which were thought to be attributable to epithelial hyperplasia. The term ectasia is defined as a dilation, expansion, or distension, all of which invoke the notion of an increase in surface area by a process of stretching. The present findings are incompatible with this definition.

Myopic regression is a main factor limiting the predictability and long-term stability of refraction after PRK. The results obtained herein revealed a statistically significant correlation between the amount of myopic regression and forward shift of the posterior corneal surface from the first week to the first year after surgery (Figure 3). Steepening in the posterior corneal surface indicates an increase in the negative power of that surface. Since refractive corneal surgery for myopic correction aims to reduce the corneal refractive power, an increase in the posterior corneal negative power adds to the effects of surgery, ie, the possible source of overcorrection. The anteroposterior corneal shift, however, should affect both corneal surfaces equally. The steepening of the anterior corneal surface means an increase in the positive refractive power. When both surfaces bulge similarly, the anterior surface exerts far greater absolute refractive changes than does the posterior surface, since the former faces the air and the latter contacts the aqueous humor. Thus, the forward shift of both corneal surfaces counteracts the effects of PRK. The forward shift of the cornea alone cannot fully explain the occurrence of regression after PRK as evidenced by the small R² value (0.11), and other factors such as epithelial hyperplasia and/or stromal remodeling should play important roles.

Nevertheless, the current study implies that forward shift of the cornea can affect the instability of refraction after corneal refractive surgery. This is especially important when considering an enhancement ablation for regression. By subtracting more tissue from the cornea, more anterior shift of the cornea may occur, counteracting the corrective effect of anterior surface flattening.

We found that PRK induced forward shifts of the cornea, which were progressive up to 6 months postoperatively and became nearly stable thereafter. Progression of anterior bulging was more prominent in those eyes with less preoperative corneal thickness and greater myopia requiring larger laser ablation. These forward shifts, however, did not represent true corneal ectasia as evidenced by the lack of progressive thinning and expansion of the cornea during the 1-year observation. Anterior movement of the cornea may add to the myopic regression after PRK.