

# Correlation of Changes in Refraction and Corneal Topography After Photorefractive Keratectomy

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## ABSTRACT

**PURPOSE:** To establish which corneal power evaluation measured with corneal topography correlates best with refractive changes after photorefractive keratectomy (PRK) for myopia.

**METHODS:** Two hundred fifty-one consecutive eyes of 171 patients who had PRK for myopia ranging from -14.80 to -0.50 D (mean  $-5.43 \pm 2.978$  D), calculated at the corneal plane, were included in the analysis. Data included preoperative and postoperative (1, 3, and 6-mo) subjective refraction and videokeratography with a Keratron Scout (Optikon 2000). Statistical analysis was performed to determine the correlation between the change in subjective refraction at the corneal plane and changes in six corneal power measurements: best fit sphere, simulated keratometry (Sim K), corneal apex, and center of the pupil (last two evaluated for axial and meridional curvatures).

**RESULTS:** The closest correlation between subjective refraction change and corneal power measurement during the three follow-up evaluations was found with Sim K ( $R^2 = 0.904; 0.889; 0.854$ ) and best fit sphere ( $R^2 = 0.919; 0.909; 0.872$ ), whereas the other measurements showed poor correlation with the different curvatures.

**CONCLUSIONS:** The best fit sphere corneal topography parameter correlated best with the refractive changes, primarily for low treatment amounts, whereas it showed a clear-cut underestimation in eyes that had undergone high dioptric treatments. [*J Refract Surg* 2004;20:478-483]

Changes in corneal topography after excimer laser photorefractive keratectomy (PRK) have been studied both in terms of qualitative changes, such as different patterns obtained after treatment<sup>1-3</sup>, as well as quantitative changes, such as the correlation between refractive and corneal power changes.<sup>4-10</sup>

Corneal topography calculates corneal power by measuring the size of projected rings reflected off the anterior corneal surface and by converting the image size into the radius of curvature or dioptric power by the use of three formulas: axial, tangential-local, and refractive formulas.<sup>8</sup>

In most articles that compare changes in manifest refraction and changes in corneal topography, evaluation has been performed using axial curvature<sup>5-7,9</sup>, or has been performed in a few eyes shortly after refractive procedures when refractive changes had not yet stabilized.<sup>8</sup> We attempt to establish which of the power changes calculated by videokeratography, utilizing axial and meridional curvatures, is most consistent with and most predictive of change in manifest refraction after PRK.

## PATIENTS AND METHODS

We studied the corneal topography of 171 consecutive patients (251 eyes) who had undergone PRK for myopia with or without myopic astigmatism; 75 were male and 96 were female. Mean age was  $33 \pm 9$  years (range 20 to 59 yr). Attempted spherical equivalent correction ranged from -14.80 to -0.50 D (mean  $-5.43 \pm 2.978$  D) calculated at the corneal plane. Preoperative and follow-up examinations at 1, 3, and 6 months included detailed ophthalmic examination with manifest refraction and videokeratography (Keratron Scout, Optikon 2000, Rome, Italy).

Patients were asked to discontinue contact lens wear for at least 1 month before undergoing the last

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refractive and topographic evaluation, which was performed a few days before the patient had PRK.

Patients with systemic and ocular diseases that might potentially interfere with the healing process of the cornea or with refractive outcome, such as diabetes, collagenopathies, dry eyes, uveitis, corneal and lens opacities, or glaucoma were excluded.

Treatments, both as sphere and as cylinder, were performed by combining objective and subjective refraction, thereby achieving best corrected visual acuity. In particular, the cycloplegic refraction was performed during the first examination, whereas the subjective refraction was performed during the last examination before surgery, taking into account the results of the cycloplegic refraction. When a discrepancy between these two methods was found, a duochrome (red-green) test was performed, and this was the final refraction. All treatments were performed under topical anesthesia with oxybuprocaine eyedrops. The lids were opened with a speculum, the epithelium was debrided with mechanical brush epithelial removal, and all treatments were performed with a 193-nm excimer laser (Nidek EC-5000, Gamagori, Japan) operating in scanning mode. After treatment, surface smoothing was performed by placing 1 drop of a 0.04% hyaluronic acid solution over the cornea, and spreading it out with a 23-gauge cannula. This technique allowed fluid to fill an eventual depression in the cornea, thus protecting the tissue from the laser pulse. At this point, a phototherapeutic keratectomy (PTK) treatment was performed, and the endpoint of the smoothing was chosen on the basis of microscopy and clinical evidence.<sup>11</sup> A bandage contact lens was applied under sterile conditions on the treated eye immediately following surgery, and remained until complete re-epithelialization. During this period, the operated eye received the following medications: diclofenac sodium 0.1% eyedrops twice a day for the first 2 days, nethylmicin preservative-free eyedrops until re-epithelialization and preservative-free artificial tears for 1 month. After re-epithelialization, clobetasone eyedrops were prescribed for all patients for 1 month in a tapered dose, as follows: 1 drop four times per day for the first week, 1 drop three times per day for the second week, 1 drop twice per day for the third week, and 1 drop once per day for the last week.

To determine the relationship between refractive and power change at the corneal plane, we used the following formula: Spherical equivalent (SEQ) corneal plane = SEQ spectacle plane/[1-(0.012 \* SEQ spectacle plane)]. These values were compared

with the difference in power obtained with videokeratography (utilizing the keratometric index of 1.3375 for converting the corneal radius in diopters) measured at different points, and by utilizing different curvatures.

Four topographies were performed on each eye, and the topography selected for the study was chosen based on the following criteria: the least eyelid coverage to allow processing of the greatest area, correct centering, correct focusing with thin, regular, continuous rings, and absence of dry spots or excess pooling of tears along the inferior lid margin.<sup>12</sup>

The difference in power by utilizing six different measurements were analyzed: best fit sphere, simulated keratometry (Sim K), corneal vertex, center of the pupil—the latter two measured with axial and meridional curvatures.

Corneal vertex is defined by the reflection of the photokeratoscope fixation light from the corneal apex to the observer; it is automatically located by the computer with a cursor on the initial image captured. Center of the pupil is automatically located by the computer with a cursor on the initial image captured. The Keratron instrument was calibrated at the start of each examination session. Refraction and the topographic analysis were performed by two independent observers. The correlation between the refractive and the measured corneal power change was assessed by linear regression analysis, and paired *t*-test.

## RESULTS

The correction achieved at 1 month was between -17.875 and -0.375 D (mean -6.5264 ± 3.73 D). At 3 months, it was between -18.30 and -0.38 D (mean -6.54 ± 3.50 D), and at 6 months it was between -18.25 and -1.50 D (mean: -6.58 ± 3.57 D). Differences in power calculated with corneal topography at the 1, 3, and 6-month follow-up are shown in Tables 1 to 3. Figures 1 to 6 show the correlation between refractive change and change in corneal power with the different methods, at the 6-month follow-up.

## DISCUSSION

An accurate assessment of corneal refractive power after excimer laser treatment has several practical applications. First, it could provide a reliable explanation about whether an undercorrection or overcorrection is due to an error in measuring refraction before surgery or in the excimer laser calibration. Second, it could be used for intraocular

**Table 1**  
**Difference Between Achieved Correction at the Corneal Plane and on Corneal Topography (D) at 1 Month After PRK for Myopia With or Without Astigmatism**

	Range	Mean	SD	P-value	Correlation Coefficient (R <sup>2</sup> )
Best fit sphere	0.0005 ~ 4.3368	0.7294	0.688	<.001	0.9192
Simulated keratometry (Sim-K)	0.0111 ~ 4.9768	0.9253	0.825	<.001	0.9099
Center of the pupil, axial	0.0105 ~ 7.1868	2.3943	1.18	<.001	0.7103
Center of the pupil, meridional	0.0048 ~ 7.3068	1.4026	1.359	<.001	0.6286
Corneal vertex, axial	0.0050 ~ 9.9605	1.9045	1.812	<.001	0.5336
Corneal vertex, meridional	0.1105 ~ 11.8105	2.3943	2.25	<.001	0.4105

**Table 2**  
**Difference Between Achieved Correction at the Corneal Plane and on Corneal Topography (D) at 3 Months After PRK for Myopia With or Without Astigmatism**

	Range	Mean	SD	P-value	Correlation Coefficient (R <sup>2</sup> )
Best fit sphere	0.0042 ~ 3.6414	0.8026	0.72	<.001	0.909
Simulated keratometry (Sim-K)	0.0007 ~ 4.0004	1.0019	0.855	<.001	0.8887
Center of the pupil, axial	0.0042 ~ 6.4299	1.5003	1.118	<.001	0.7071
Center of the pupil, meridional	0.0157 ~ 6.5229	1.6353	1.255	<.001	0.6207
Corneal vertex, axial	0.0030 ~ 10.9405	2.3844	1.867	<.001	0.4408
Corneal vertex, meridional	0.0273 ~ 11.9105	2.7240	2.233	<.001	0.3554

**Table 3**  
**Difference Between Achieved Correction at the Corneal Plane and on Corneal Topography (D) at 6 Months After PRK for Myopia With or Without Astigmatism**

	Range	Mean	SD	P-value	Correlation Coefficient (R <sup>2</sup> )
Best fit sphere	0.0037 ~ 3.3222	0.8515	0.775	<.001	0.872
Simulated keratometry (Sim-K)	0.0065 ~ 3.9906	1.0412	0.915	<.001	0.854
Center of the pupil, axial	0.0008 ~ 6.4860	1.647	1.284	<.001	0.6587
Center of the pupil, meridional	0.0078 ~ 6.8160	1.571	1.238	<.001	0.6338
Corneal vertex, axial	0.0012 ~ 10.2562	2.9908	2.194	<.001	0.3046
Corneal vertex, meridional	0.0089 ~ 12.7662	3.6069	2.819	<.001	0.202

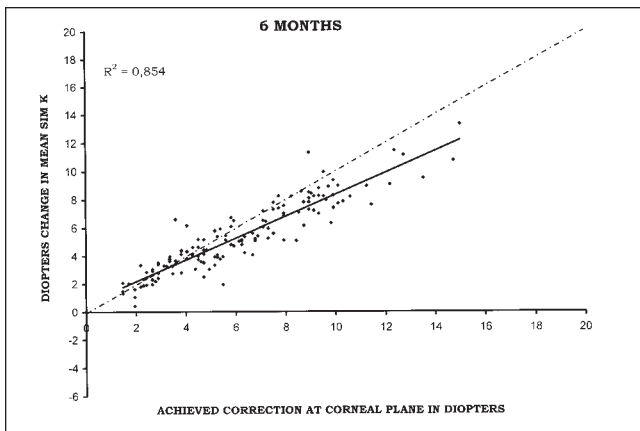
lens calculation in patients who had previously undergone refractive surgery, thus avoiding the need for making difficult calculations.<sup>13,14</sup> Third, it might help to design better ablation profiles for excimer laser refractive surgery. Other authors have tried to find the most accurate assessment, but results have not been conclusive.

In determining the correlation between achieved spherical refractive correction and topography power changes at the ablation center, pupil center, and point of greatest power changes on the topography map, Hersh and colleagues<sup>7</sup> found a tendency to overestimate achieved refractive correction by the topography map for myopia corrections of -5.00 D or

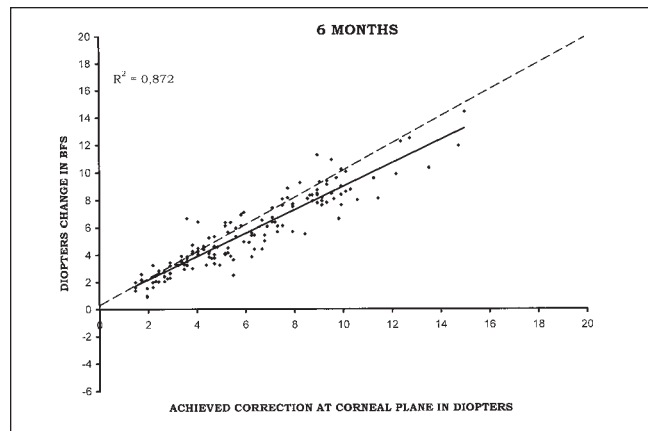
less, and a tendency to underestimate refractive corrections greater than -5.00 D.

These results were not confirmed by Rosa and colleagues<sup>9</sup>, who in determining the correlation between the achieved spherical refractive correction and the topography power changes at the ablation center, vertex normal with the axial curvature and within the 3-mm pupil zone (Effective Refractive Power), found in all evaluated points a mean underestimation of about 25% to 30%, greater in cases of higher corrections.

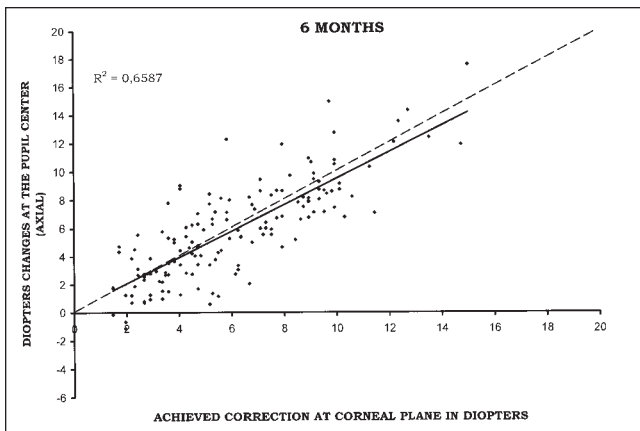
When determining the correlation between the achieved spherical refractive correction and topography power changes utilizing the meridional



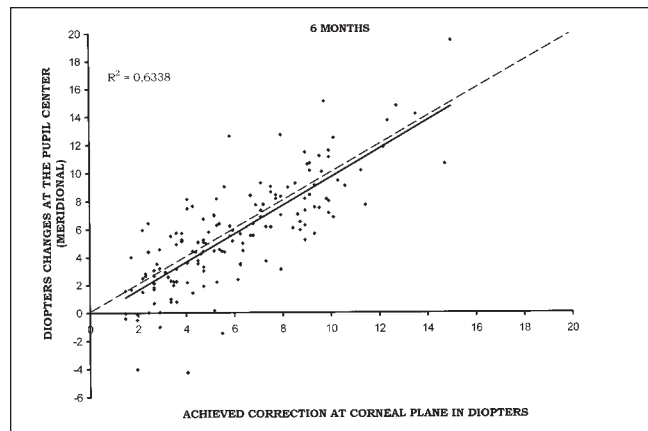
**Figure 1.** Correlation between the difference in power calculated with Sim-K and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.



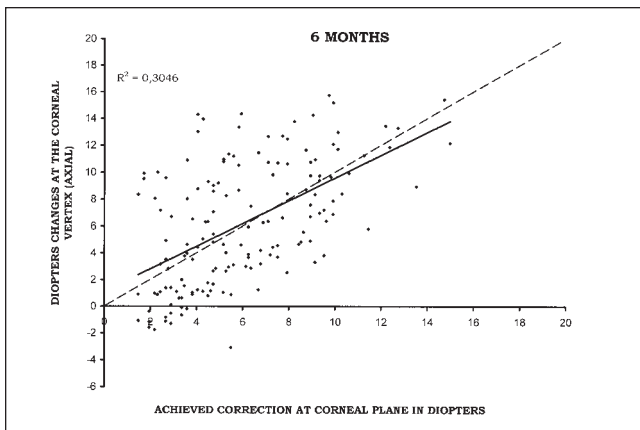
**Figure 2.** Correlation between the difference in power calculated with best fit sphere and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.



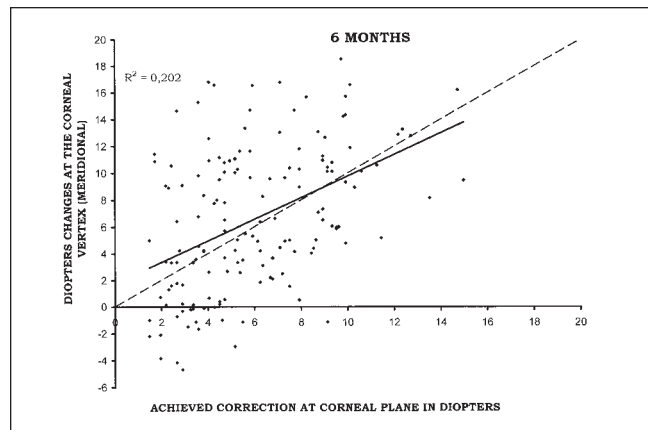
**Figure 3.** Correlation between the difference in power calculated at the pupil center, with the axial curvature, and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.



**Figure 4.** Correlation between the difference in power calculated at the pupil center, with the meridional curvature, and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.



**Figure 5.** Correlation between the difference in power calculated at the corneal vertex, with the axial curvature, and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.



**Figure 6.** Correlation between the difference in power calculated at the corneal vertex, with the meridional curvature, and achieved correction at the corneal plane 6 months after PRK for myopic and/or myopic astigmatism.

curvature formula, Peter and colleagues<sup>10</sup> found an underestimation that increased with the amount of myopic correction. When determining correlation between the achieved spherical refractive correction and topography power changes with Sim K, central K, and pupil K, they found a statistically significant difference.

Utilizing 14 corneal topography parameters, Hugger and colleagues<sup>8</sup> found a close correlation between computerized keratometry values and refraction, with the exception of instantaneous simulated keratometry, but they suggested that further evaluations be done because their study included only 27 eyes and follow-up of 1 month after refractive surgery, when there might be a greater amount of irregular astigmatism; later wound healing changes could alter this relationship.

In this study, we evaluated six measurement procedures obtained with a Keratron Scout: best fit sphere, simulated keratometry, corneal vertex, center of the pupil, with the latter two measured with axial and meridional curvatures. We chose these measurements because they are not influenced by the operator; they are automatically calculated by the computer. Moreover, the center of the pupil is automatically located by the computer with a cursor on the initial image captured.

The best fit sphere method was described by Maloney and associates<sup>16</sup> for measuring refractive power of the cornea based on all the points on the corneal topography in the central 4 mm of the cornea, and this method was then improved to predict the corneal refractive power by taking into account the corneal asphericity and the Stiles Crawford effect<sup>17</sup> and is automatically calculated by the machine.

The corneal vertex is defined by the reflection of the photokeratoscope fixation light from the corneal apex to the observer; even though it may or may not coincide with the visual axis, it provides an objective and reproducible point on the corneal surface<sup>18</sup> as it is automatically located by the computer with a cursor on the initial image captured.

Our study shows that local values are poor when predicting overall refractive effect. This is to be expected because retinal image formation is an integrated effect of the entire portion of the optical system of the eye in the area not masked by the iris, ie, in the pupil area. This could explain why best fit sphere and Sim-Ks show a better correlation.

Regarding best fit sphere, although the data grouped well, the slope of the fit was not 1:1; this may be because of the inclusion of non-ablated

corneal surface in the fit. However, the correlation was fairly good and this may reflect the fact that we used fairly large ablation zones, and so the topographer did not measure too much corneal surface outside the ablation zone.

One of the criticisms of our study could well be that the refractive index (1.3375) used to calculate the difference in power is not valid after PRK and laser in situ keratomileusis (LASIK) because these procedures change the relationship between the anterior and posterior surface of the cornea.<sup>11,20</sup> For this reason, some authors suggest using a refractive index (n) of 1.376, whereas others<sup>11,20</sup> suggest the higher value n = 1.40838, but unfortunately, thus far no agreement has been reached regarding which refractive index should be used. The purpose of our study was not to find the correct refractive index to be used, but to check which of the above mentioned parameters better correlated with refractive changes.

We compared data with subjective refraction; in theory comparing such data with an objective measurement such as wavefront analysis would be more accurate, but to the best of our knowledge, this method has not been validated in clinical studies, and some authors have shown that the information made available with current machines may confound clinical diagnosis.<sup>19</sup>

Although this study was retrospective, we are unlikely to have introduced bias for the following reasons: refraction and topographic analysis were performed by two independent observers, and all analyzed videokeratographic points were performed by computer analysis and matched at the end of the study, so the refraction on the chart would not bias the results of the corneal topography.

We did not evaluate the center of the ablation and the point of greatest flattening within the treatment zone—sometimes located away from the visual axis—and the goal of our study was correlation with achieved correction and not with attempted correction. It might have been more useful to study these parameters<sup>6</sup> as well.

The topographic indices with a correlation closest to change in dioptric power are those that average power values over a wide measurement area (on more data points), and use axial assumptions. However, all the available parameters did not effectively reflect changes in corneal power after refractive surgery; new algorithms that take into account different refractive indices should be developed in order to better evaluate corneal power in eyes after refractive surgery.

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