Computerized Scheimpflug densitometry as a measure of corneal optical density after excimer laser refractive surgery in myopic eyes

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PURPOSE: To evaluate changes in anterior corneal optical density and the refractive index after photorefractive keratectomy (PRK) using a rotating Scheimpflug system.

SETTING: Department of Ophthalmology, University Federico II, Naples, Italy.

DESIGN: Comparative case series.

METHODS: Anterior corneal optical density was evaluated with a rotating Scheimpflug system at baseline and 3 months and 12 months after PRK in eyes with a refractive error between −6.00 diopters (D) and −12.00 D (study group). A control group of unoperated eyes with the same refraction range was used to calculate corneal optical density and the Gladstone-Dale constant in unoperated eyes using the Gladstone-Dale formula. In the study group, changes in the anterior corneal optical density were evaluated over time and variations in the anterior corneal refractive index were obtained using the Gladstone-Dale constant.

RESULTS: The study group comprised 37 eyes and the control group, 200 eyes. In the study group, the mean anterior corneal optical density and refractive index, respectively, were 27.71 $\pm$ 4.39 and 1.360 $\pm$ 0.05 at baseline, 37.812 $\pm$ 12.31 and 1.491 $\pm$ 0.16 after 3 months (P<.001 compared with baseline), and 26.29 $\pm$ 4.93 and 1.341 $\pm$ 0.06 after 12 months (P=.03 compared with baseline). The mean corneal optical density in the control group was 27.71 $\pm$ 4.31 (SD), and the resultant Gladstone-Dale constant was 0.013.

CONCLUSION: An early increase and a subsequent reduction in anterior corneal optical density and the refractive index were present in myopic eyes during 1 year after PRK.

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The aim of laser refractive surgery is to focus light rays on the retina by changing the refractive power of the anterior cornea. Regression of the refractive effects of photorefractive keratectomy (PRK) has been reported[1,2] and attributed to changes in stromal thickness resulting from corneal wound repair.[3–5]

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In this study, we used Scheimpflug imaging to measure corneal optical density before and after excimer refractive surgery in myopic eyes. The corneal optical density changes allowed us to evaluate variations in the corneal refractive index resulting from PRK.

PATIENTS AND METHODS

This prospective nonrandomized study evaluated changes in the mean anterior corneal optical density in consecutive myopic eyes with a refractive error between −6.00 diopters (D) and −12.00 D that had PRK between November 2006 and March 2008 (study group). A control group of 200 unoperated eyes with a refractive error between −6.00 D and −12.00 D was also evaluated. The study was performed according to the ethical principles of the Declaration of Helsinki.

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The Gladstone-Dale formula was used to obtain the mean anterior corneal refractive index as follows:

$$K = (n - 1)/d$$

where K is the Gladstone-Dale constant, n is the corneal refractive index and d is the corneal density.[6,7] In the control group, the Gladstone-Dale constant K was calculated using the normal anterior corneal refractive index of 1.376.[8] In operated eyes, the mean anterior corneal refractive index was obtained using the actual mean anterior corneal optical density and the Gladstone-Dale constant as measured in the control group. The primary study endpoint was to assess the changes in anterior corneal optical density 3 months and 12 months after PRK. The secondary study endpoint was to calculate changes in the anterior corneal refractive index after PRK.

Surgical Technique

The same surgeon performed all PRK procedures using a conventional excimer laser system (Allegretto 400 Hz Wavelight excimer laser, WaveLight, Inc.; fluence 180 mJ/cm^2 per pulse at 10 Hz) and topical anesthesia of tetracaine 1.0% (3 drops administered at 5-minute intervals). The epithelium was removed by gentle scraping with a blade, after which the excimer laser ablation was performed. The optic zone was 6.0 mm with a transition zone extending to 9.0 mm. Postoperatively, gentamicin eyedrops were used and a patch was applied.

Scheimpflug Camera System

Preoperatively and 3 months and 12 months after surgery, the mean anterior corneal optical density was determined using the Pentacam 70700 system (software version 6.02r10, Oculus Inc.) after 10 consecutive measurements in each eye. This noninvasive system measures and characterizes the anterior segment using a rotating Scheimpflug camera. The system determines anterior and posterior corneal topography, corneal thickness, anterior chamber depth and angle, and cornea and lens optical density.[9–11] The Scheimpflug principle has been established in the assessment of lens thickness and densitometry.[12] The rotating Scheimpflug camera takes 100 images with 500 measurement points on the anterior and posterior corneal surfaces over a 180-degree rotation. The elevation data from these images are combined to form a 3-D reconstruction of the corneal structure. After all this information is processed, the internal software provides a large number of different calculations.

The same measurement procedure was used in all cases. The patient was asked to blink twice and then look at the fixation device before each measurement. The examiner adjusted the joystick until perfect alignment was shown. Then, the system automatically took 100 images of the cornea within a 2-second period. Acceptable maps had at least 10.0 mm of corneal coverage with no extrapolated data in the central 9.0 mm zone. The system automatically provides optical density values (intended as light scattering) for the cornea and the lens, according to the light-scattering intensity of the corneal and lens layers. On the 3-D Scheimpflug image, the density value is shown to the right of the densitogram. The heights of green bars indicate densities of cornea and lens. On positioning the line across the cornea, the upper value shows the corneal density value, which is marked by a blue line. The density measurement is standardized from 0 to 100 units. This study analyzed only values for the highest corneal densitometry peak, which corresponds to the anterior cornea (Figure 1). All scans were centered on the pupil center.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 17.0, SPSS, Inc.). The mean corneal optical density values at baseline in the study group and in the control group were compared using the Student t test. To determine whether significant changes occurred in the study group from baseline to 3 and 12 months postoperatively, the repeated-measure analysis of variance (with Dunnett post hoc test) was used.

RESULTS

The study group comprised 34 eyes of 34 patients (16 women, 18 men) with a mean age of 32.2 years ± 7.8 (SD). At baseline, the mean refractive error was −8.58 ± 1.43 D, the mean corneal thickness (CCT) was 549 ± 41 μm, the mean anterior corneal optical density was 27.71 ± 4.39, and the mean anterior corneal refractive index was 1.360 ± 0.05.

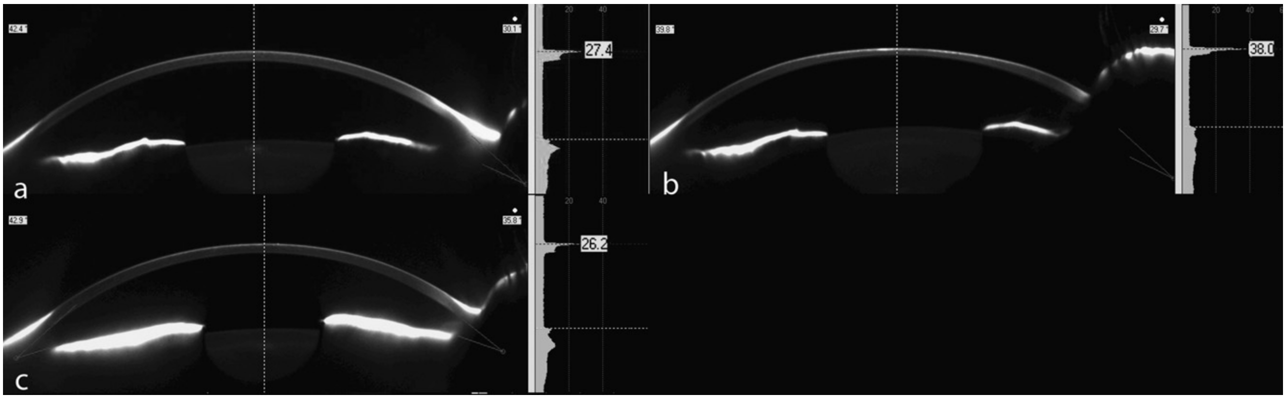

Figure 1. Scheimpflug densitometry reading in a myopic eye at baseline (*A*), 3 months after PRK (*B*), and 12 months after PRK (*C*). The highest densitometry peak from the top corresponds to the anterior corneal densitometry value.

The control group comprised 200 eyes of 100 patients (53 women, 47 men) with a mean age of 35.22 ± 9.55 years. The mean spherical refractive error was −8.48 ± 2.76 D, the mean CCT was 553 ± 45 μm, and the mean corneal optical density was 27.71 ± 4.31, with a resultant Gladstone-Dale constant of 0.01357.

The mean age, preoperative anterior corneal optical density, and preoperative spherical equivalent refraction were not statistically significantly different between the study group and the control group.

Three months after PRK, the study group had a mean refractive error of −0.75 ± 1.3 D, a mean CCT of 464 ± 31 μm, a mean anterior corneal optical density of 37.812 ± 12.31, and a mean anterior corneal refractive index of 1.491 ± 0.16 (Figure 2). The increase in anterior corneal optical density and the refractive index and the reduction in CCT compared with baseline were statistically significant ($P<.001$). The correlation between the change in refractive error and the change in anterior corneal optical density compared with baseline was 0.31 (Spearman ρ) ($P=.4$).

Twelve months after PRK, the study group had a mean refractive error of −0.25 ± 0.88 D, a mean CCT of 480 ± 29 μm, a mean anterior corneal optical density of 26.291 ± 4.93, and a mean anterior corneal refractive index of 1.341 ± 0.06 (Figure 2). The reductions in anterior corneal optical density and the refractive index from baseline ($P=.035$ and $P=.037$, respectively) and from the 3-month visit ($P<.001$) were statistically significant. The CCT was statistically significantly reduced from baseline; however, there was a statistically significant increase over the 3-month value ($P<.001$). The correlation between the change in refractive error and the change in anterior corneal optical density compared with baseline was 0.38 (Spearman ρ) ($P=.28$).

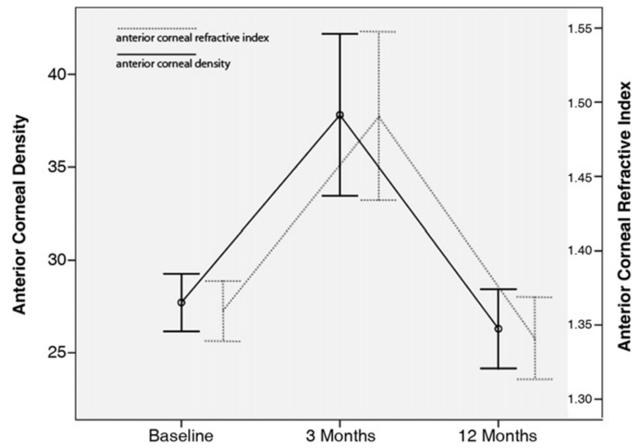

Figure 2. Anterior corneal optical density and refractive index in 37 myopic eyes at baseline and 3 and 12 months after PRK (means and 95% confidence interval). The double-ordinate plot contains a left axis scale for anterior corneal density and a right axis scale for anterior corneal refractive index.

DISCUSSION

To our knowledge, this is the first report of using the Pentacam Scheimpflug system to evaluate changes in optical density and the refractive index of the anterior cornea after PRK. A previous study[13] used the same Scheimpflug system and found a similar increase in corneal density during the first 12 weeks after laser in situ keratomileusis (LASIK) and epithelial LASIK.

In this study, the Scheimpflug system was used to measure anterior corneal optical density in operated eyes and in a control group of unoperated eyes. The refractive index was measured using the Gladstone-Dale formula. The densitometry function provides an objective quantitative assessment by measuring the light scatter of the cornea and the lens, which becomes visible by illumination with blue light (wavelength 475 nm). In a recent study by Kirkwood et al.,[14] repeatability of Pentacam Scheimpflug lens densitometry was found to be high within observers (eg, repeatability coefficient of 3-D metric = 0.46) and between observers (repeatability coefficient of 3-D metric = 0.53).

In our study, there was an increase in anterior corneal optical density and the refractive index 3 months after PRK, while a reduction was measured at the 12-month visit. Central corneal thickness decreased at the 3-month visit and increased at the 12-month visit, as reported in other studies.[15–17] In vivo confocal microscopy has shown that there is a significant amount of keratocyte-mediated stromal tissue deposition after PRK. On the other hand, the corneal epithelium appeared to regain its preoperative thickness 1 year after PRK without contributing significantly to the refractive changes.[3,18] The biomechanical and refractive properties of the cornea are influenced by the size and organization of stromal collagen fibrils, which appear more closely packed in the prepapillary cornea than in the peripheral cornea.[19] Photorefractive keratectomy has been reported to induce a more aggressive wound-healing response than LASIK and to lead to more myopic regression and more haze development.[20,21] Changes in the refractive index have been correlated with the degree of corneal stromal hydration after excimer photoablation.[22] The changes in anterior corneal optical density and the refractive index and the progressive increase in postoperative corneal thickness after PRK in our study could also suggest postoperative stromal remodeling.

A control group was used to measure the normal anterior corneal optical density and to calculate the Gladstone-Dale constant for the unoperated human anterior cornea. The actual anterior corneal optical density values and the Gladstone-Dale constant were used in the PRK group to obtain a mean refractive index of the anterior cornea. To measure the Gladstone-Dale constant in the control group, we referred to the Hamed et al.[8] study in which the authors used a refractive index of 1.376 for the anterior surface of the normal human cornea when using the Gaussian formula. In a previous study, Patel et al.[23] found a similar in vitro refractive index of 1.380 $\pm$ 0.005 for the anterior corneal stroma and reported that different layers of the cornea have slightly different refractive indices. The Pentacam system is based on the principles of Scheimpflug photography and has shown good intraobserver and interobserver repeatability.[9,11,13] Twelve months after PRK, the reduction in the refractive index over the baseline value was relatively small (−0.8%), and a low correlation was found between the changes in refractive error and the changes in anterior corneal optical density. Nevertheless, these changes affect the anterior corneal surface, which accounts for the greater part of the corneal refractive power. Therefore, the changes in the anterior cornea are responsible for most of the postoperative changes in refractive error.

After refractive photoablation, calculation of intraocular lens (IOL) power for cataract surgery is problematic because it is difficult to accurately measure corneal refractive power. The IOL power calculations after refractive surgery are inaccurate because surgical procedures such as PRK and LASIK affect the relationship between the anterior and posterior surfaces of the cornea.[24] Keratometers are calibrated for a particular corneal index (typically 1.3375), which assumes that the corneal thickness and the relationship between the anterior and posterior surfaces are constant. After PRK, a refractive index of 1.3375 underestimates corneal power with keratometry and corneal topography analysis by 20% to 25%.[25–29] According to our results, anterior corneal optical density significantly changed during the 12 months after refractive surgery. A mean reduction in the anterior corneal refractive index by 0.02 was present 12 months after PRK. In a previous study,[30] we predicted a similar theoretic reduction in the relationship to axial length in myopic eyes treated with small ablation zone PRK and suggested a correction factor to calculate IOL power for myopic eyes treated with PRK.

A limitation of this study is it was not possible to assess a stabilization of the optical density changes 12 months after PRK. Further studies with a longer follow-up are planned.

In conclusion, we found an early increase and a subsequent reduction in anterior corneal optical density and the refractive index on examination with a Scheimpflug imaging system during the 12 months after PRK. These changes were likely the result of stromal wound-healing responses and should be considered when calculating IOL power after refractive surgery.

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