Contrast Sensitivity and Glare Disability After Radial Keratotomy and Photorefractive Keratectomy

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Objectives: To study the effects of radial keratotomy (RK) and photorefractive keratectomy (PRK) on contrast sensitivity and glare disability using 4 different devices, and to correlate subjective complaints with objective scores of visual performance.

Methods: Preoperative contrast sensitivity for 30 eyes undergoing RK and 30 eyes undergoing PRK was compared with contrast sensitivity at 1, 3, and 6 months postoperatively using the CSV 1000, MCT (Multivision Contrast Tester) 8000, and Pelli-Robson chart. The BAT (Brightness Acuity Tester) and MCT 8000 were used to test for daytime and nighttime glare disability, respectively. At 3 and 6 months postoperatively, a questionnaire was administered to assess visual performance subjectively.

Results: Contrast sensitivity decreased after RK and PRK up to the sixth postoperative month, while glare disability was significantly increased at 1 month after PRK as determined by the MCT 8000 and the BAT, and at the third and sixth months after RK using the MCT 8000. Compared with RK, PRK significantly decreased contrast sensitivity as measured with the MCT 8000 at all spatial frequencies 1 month postoperatively. No significant difference in visual performance between patients undergoing RK and PRK was observed with the CSV 1000, the Pelli-Robson chart, or the BAT up to 6 months postoperatively. No consistent difference was found between glare disability scores of patients undergoing RK and PRK when measured with the MCT 8000. Subjective reports of problems with night driving and blurring correlated only with glare disability scores of the MCT 8000 3 months after RK.

Conclusions: Both RK and PRK reduce contrast sensitivity and cause glare disability; however, the relative effect is highly dependent on the time postoperative testing is performed and the instrument used for testing. Contrast sensitivity and glare disability, as measured by the instruments used in this study, do not accurately reflect patients’ subjective assessment of visual performance in daily life.


Most clinical studies assess the safety of refractive surgical procedures by measuring the change in best spectacle-corrected visual acuity. Visual acuity, however, is a crude measure of visual performance. Visual acuity is usually measured by determining a person’s ability to resolve fine spatial detail using high-contrast targets (black figures on a white background), such as Snellen letters, numbers, or Landolt C rings. The contrast level of these targets approaches 100%. In everyday life, however, such high-contrast targets are rarely encountered, and patients who score well on traditional visual acuity tests may complain of poor vision in everyday situations.1 Such patients are believed to have decreased contrast sensitivity (CS), which impairs their ability to identify objects with low contrast under low lighting conditions.

Contrast sensitivity is defined as the ability to detect differences in luminance between adjacent areas. Contrast sensitivity tests determine the threshold of contrast required to identify a target.2 The target may be letters or sine wave gratings. The latter, which are most widely used, consist of alternating dark and light bars. These bars are specified according to their size (spatial frequency), contrast, and orientation. The CS function is a curve produced by plotting the minimum or threshold contrast (on the y-axis) required to identify a target against spatial frequency of the target (on the x-axis).3-6

Standard visual acuity measurement does not adequately test visual performance under bright indirect lighting conditions such as that of a bright sunny day or headlights from an oncoming car. A pa-
PATIENTS AND METHODS

Sixty consecutive eyes undergoing RK (30 eyes) or PRK (30 eyes) were enrolled in the study. Inclusion criteria for both groups were the same: spherical equivalent of cycloplegic refraction between 1.50 and 6.00 diopters of myopia, astigmatism of 1.25 D or less, the absence of ocular disease, and age 18 years or older. Patients in the RK group were excluded from the study if they had astigmatic keratotomy as an enhancement to their initial surgery. Each excluded patient was replaced by the next eligible consecutive patient so that the final number of eyes in the RK group would be 30. However, enhancement of the radial incisions did not exclude a patient from the study.

Detailed ocular history and medical history were obtained and a complete ophthalmological examination, including manifest and cycloplegic refraction, was performed preoperatively. Uncorrected and best spectacle–corrected visual acuity was measured with Early Treatment Diabetic Retinopathy Study (ETDRS) charts. Informed consent was obtained from each patient before enrollment in the study.

Surgical procedures were performed with topical anesthesia by 1 of 2 experienced surgeons (R.D.S., K.P.T.). Radial keratotomy consisted of 4 to 8 radial bidirectional incisions with a central clear zone of 3- to 4.5-mm diameter. Photorefractive keratectomy was performed using an excimer laser (Summit Excimer UV 200/OmniMed Excimer Laser, Summit Technology Inc, Waltham, Mass). After mechanically debriding the central epithelium, photodestruction was performed using zones of 5 mm (20 eyes) or 6.5 mm (10 eyes), a repetition rate of 10 Hz, and fluence of 180 mJ/cm².

All patients had a complete ophthalmological examination at 1, 3, and 6 months postoperatively. The degree of subepithelial haze after PRK (none, trace, mild, moderate, and severe) was determined by comparison to reference photographs.

CS AND GD TESTING METHODS

Four devices were used to test CS and GD preoperatively and at the first, third, and sixth postoperative months. All tests were performed with the patient wearing his or her manifest refraction.

The CSV 1000 (VectorVision, Dayton, Ohio) consists of a retroilluminated translucent chart with a light level that is automatically adjusted to 85 candelas per square meter (cd/m²). The chart presents vertical sine wave gratings at 4 spatial frequencies: 3, 6, 12, and 19 cycles per degree (cpd). Each row presents 8 pairs of circular patches containing sine waves of a single spatial frequency. For each pair, 1 patch presents a grating and the other patch is blank. Contrast of the gratings decreases from left to right across the row. At a testing distance of 2.4 m (8 ft), the patient was asked to indicate whether the grating appeared in the top patch or the bottom patch for each pair. The contrast level of the last correct response in each row was recorded as the contrast threshold.

The MCT (Multivision Contrast Tester) 8000 (Vistech Consultants, Dayton) is a table unit that has 5 slides for CS testing. Each slide has 7 sine wave grating patches arranged in a circle. The contrast of the gratings on each slide decreases from patch 1 to 7 while the spatial frequency remains constant (1.5, 3, 6, 12, or 18 cpd). The gratings randomly vary in their orientation (vertical or tilted to the left or to the right). For CS testing, target illumination was calibrated by the examiner to 130 cd/m². At a viewing distance of 45 cm, the observer was asked to report the orientation of the lowest contrast patch visible in each slide. This was considered the contrast threshold for that

Continued on next page

RESULTS

The mean (±SD) age of patients was 44.4±7.9 in the RK group and 37.8±8.4 in the PRK group. The mean preoperative manifest refraction in both groups was −3.9±1.4.
frequency. Glare testing was performed in the same way, but target illumination was decreased to 3.5 cd/m². A central light of 75 lux was used as a glare source to simulate an automobile headlight.

The Pelli-Robson chart (Clement Clark, Columbus, Ohio) is a wall chart that has 8 rows of 6 Sloan letters. The letter size is equivalent to the 20/60 Snellen line. The letters are arranged in groups of 3 (ie, triplets). The contrast decreases from one triplet to the next by steps of about 0.15 log units, ranging from about 100% contrast at the upper left corner to 0.9% contrast at the lower right corner. The acceptable range of chart illumination is between 60 and 20 cd/m². At 1 m from the chart, the patient was instructed to make a single attempt to name each letter on the chart, starting with the dark letters in the upper left-hand corner. Every letter read correctly adds 0.05 log units to the score.

The BAT (Brightness Acuity Tester, Mentor O&O, Santa Barbara, Calif) consists of a 60-mm-diameter hemisphere with a white diffusing surface and a 12-mm central aperture. Using the medium intensity brightness (2500 foot-candles), the patient was instructed to hold the BAT vertically so that the ETDRS chart could be seen through the central aperture and the best-corrected visual acuity was measured.

Patients in both groups were asked to respond to a questionnaire about the quality of their vision at the postoperative 3- and 6-month visits. Patients were asked whether their vision was any different at night than during the day and to compare the quality of their vision in the treated eyes with their vision prior to surgery. They were also asked to rate the following measures on a 5-point scale: satisfaction with quality of vision, the severity of glare, problems driving at night, and blurring of vision. In addition, patients were asked if they had problems with glare in 21 different situations.

Photorefractive keratectomy significantly decreased CS at 1.5 cpd at the first and sixth months, 3 cpd at the first and sixth months, 6 cpd at all visits, 12 cpd at the first month, and 18 cpd at the first month. Photorefractive keratectomy tended to reduce CS early (1 month) and at low and middle spatial frequencies. Photorefractive keratectomy consistently reduced CS more than RK, reaching statistical significance at 1 month at all spatial frequencies.

Using the Pelli-Robson chart, CS was significantly decreased at 6 months after RK and at 1 month after PRK. There was no statistically significant difference between the effect of the 2 procedures on CS using this test.

**GLARE TESTING RESULTS**

Radial keratotomy consistently reduced CS with glare as measured with the MCT 8000 (Table 2). This effect was significant at the third and sixth postoperative months at all spatial frequencies and was greater at higher spatial frequencies. Photorefractive keratectomy significantly reduced CS with glare at 1 month. The effect seemed to persist with time at lower spatial frequencies, but there was a trend toward recovery of CS at higher spatial frequencies. The 2 procedures were comparable at low spatial frequencies. Photorefractive keratectomy reduced CS with glare more than RK at the first month, while RK reduced it more at the 3- and 6-month visits.

The BAT showed no significant effect of RK on visual acuity under the effect of glare at any postoperative visit, while PRK caused a statistically significant reduction in visual acuity under the effect of glare at 1 month, with partial recovery at 3 and 6 months. There was no statistically significant difference in the change in visual acuity under the effect of glare after either surgical procedure at any postoperative visit. However, visual acuity with glare was consistently better after RK than after PRK at all visits.

**QUESTIONNAIRE**

Three months after PRK, a significant negative correlation was found between the mean change in CS at high spatial frequencies and (1) the number of glare situations using the CSV 1000, and (2) the scores of blurring using the MCT 8000. This significant correlation was not found 6 months after PRK. No consistent significant correlation was found between the scores of the questionnaire and (1) the mean change in CS at any spatial frequency using all instruments after RK, and (2) the mean change in visual acuity score using the BAT after both procedures.

**STATISTICAL METHODS**

All CS data (with and without glare) were converted to a logarithmic scale and analyzed by 2 methods. In the first method, a paired t test was used to compare preoperative and postoperative means of CS at each spatial frequency at each postoperative visit, and to compare the mean change in CS at each spatial frequency at each postoperative visit after both procedures. In the second method, the mean percent change in CS was calculated after averaging the percent change in CS from the preoperative value at all spatial frequencies using the following formula: percent change = \([\text{postoperative value} – \text{preoperative value}] \times [100/\text{preoperative value}]\). The mean percent change after both procedures was then compared at each follow-up visit using a t test. This method has the advantage of producing a single value for CS at each visit, which facilitates comparison of CS measured by multiple devices at multiple spatial frequencies. However, this method did not permit analysis of CS at particular spatial frequencies.

Brightness acuity test results were analyzed using a paired t test to compare (1) the postoperative mean best-corrected visual acuity under the effect of glare at each visit with its preoperative value and (2) the mean change in mean best-corrected visual acuity under the effect of glare after RK with the corresponding value after PRK.

The mean percent change in CS after both procedures was correlated with the surgical variables using a correlation coefficient. A t test was used to compare the mean percent change in CS of eyes with different degrees of haze after PRK. The scores of the questionnaire were compared with the mean change in CS at each spatial frequency and the mean change in visual acuity at the third and sixth postoperative months.
SURGICAL VARIABLES

There was no statistically significant correlation between percent change in CS and either the number of radial incisions or the diameter of the central clear zone in RK. Also, no statistically significant correlation was found between the percent change in CS and either the number of pulses or the diameter of the ablation zone in PRK.

SUBEPITHELIAL HAZE AFTER PRK

No statistically significant correlation was found between the percent change in CS and the severity of subepithelial haze at any visit after PRK. No eyes with mild or moderate haze were observed in the first month. In the third month, eyes with no haze and trace haze were considered one group and eyes with mild and moderate haze were considered another group (due to the small number of eyes with each degree of haze). There were only 18 eyes at the 6-month follow-up visit when the statistical analysis was performed. However, the presence of only 3 eyes with mild or moderate degree of haze at this visit indicates that haze faded with time.

COMMENT

CS AFTER RK AND PRK

In general, CS decreased after RK and PRK when measured with the 3 devices used in the study. However, the

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The reduction in CS up to 6 months after RK is similar to the effect reported by previous investigators. Krasnov et al\textsuperscript{10} observed a statistically significant decrease in CS after RK compared with baseline values during the first month after surgery, a minimal difference 2.5 to 4 months after surgery, and no difference 10 to 12 months after surgery. The Prospective Evaluation of Radial Keratotomy (PERK) investigators found an initial, statistically significant decrease in CS in the eyes that were operated on compared with the contralateral eyes that were not operated on. However, this difference disappeared by about 24 months.\textsuperscript{11} The PERK investigators considered the average CS differences between the operated- and unoperated-on eyes not to be clinically meaningful (ie, not to affect visual performance), since CS values for the surgically treated and untreated eyes were within the range of previously published reports of normative populations.\textsuperscript{15,16} Tomlinson and Caroline\textsuperscript{12} found that the CS function was significantly reduced 1 year postoperatively in the RK-treated eyes compared with eyes that did not undergo RK. In contrast to the previous results, Olsen and Anderson\textsuperscript{13} found no statistically significant change in CS 1 month after RK using the MCT 8000. They did not report CS data beyond 1 month. Their results are similar to our results obtained with the MCT 8000.

Loss of CS after RK may be explained by light scattering from the tips of the radial scars and irregular astigmatism in or near the central clear zone.\textsuperscript{10} In time, the radial scars become thinner and less dense\textsuperscript{17} and the central clear zone regains its regularity. This may explain the return of CS to its preoperative value after about 1 year.

The reduction of CS after PRK in our study is similar to that observed by Ambrosio et al,\textsuperscript{18} who found a loss of CS at intermediate spatial frequencies 1 month after PRK. Six months after surgery, however, eyes in their PRK group (which matched the myopic range in our study) showed a full recovery of static CS function but a persistent sensitivity loss for dynamic patterns.\textsuperscript{18} In our study, dynamic CS was not measured, and CS was still lower than its preoperative value at 6 months after PRK when measured with all devices. Ficker et al\textsuperscript{19} found reduced CS with the Pelli-Robson chart at 12 months postoperatively. This is similar to our results with the Pelli-Robson chart. However, this reduction was statistically

### Table 2. Glare Disability Results\textsuperscript{*}

<table>
<thead>
<tr>
<th>Test (cpd)</th>
<th>Time</th>
<th>Glare Mean (SD)</th>
<th>Mean Change From Preop</th>
<th>P†</th>
<th>Mean Change From Preop</th>
<th>P†</th>
<th>RK vs PRK, P for Mean Change</th>
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<td>1.6 (0.2)‡</td>
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<td>...</td>
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<td></td>
<td>1 mo§</td>
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<td>.10</td>
<td>1.4 (0.4)</td>
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<tr>
<td></td>
<td>6 mo</td>
<td>1.4 (0.3)</td>
<td>-0.2</td>
<td>.02</td>
<td>1.4 (0.1)</td>
<td>-0.1</td>
<td>.05</td>
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<td>1 mo</td>
<td>1.8 (0.2)</td>
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<td>.04</td>
<td>1.7 (0.4)</td>
<td>-0.1</td>
<td>.06</td>
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<tr>
<td></td>
<td>3 mo</td>
<td>1.8 (0.3)</td>
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<td>.002</td>
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<tr>
<td></td>
<td>1 mo</td>
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<td>.50</td>
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<td>-0.3</td>
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<td>-0.2</td>
<td>.02</td>
<td>1.5 (0.4)</td>
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<tr>
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<td>1.4 (0.4)</td>
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<td>...</td>
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<tr>
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<td>1 mo</td>
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<td>-0.1</td>
<td>.20</td>
<td>0.5 (0.3)</td>
<td>-0.2</td>
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<td>-0.3</td>
<td>.002</td>
<td>0.7 (0.4)</td>
<td>-0.1</td>
<td>.90</td>
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<tr>
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<td>6 mo</td>
<td>0.6 (0.4)</td>
<td>-0.4</td>
<td>&lt;.001</td>
<td>0.7 (0.4)</td>
<td>-0.06</td>
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<td>Preop</td>
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<td>...</td>
<td>...</td>
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<tr>
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<tr>
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<td>0.002</td>
<td>.90</td>
<td>-0.04</td>
<td>0.05</td>
<td>.20</td>
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</table>

*cpd indicates cycles per degree; MCT, Multivision Contrast Tester 8000; and BAT, Brightness Acuity Tester. Statistically significant values (P < .05) are shown in boldface.
†Preoperative (preop) vs postoperative.
‡Mean glare disability in log units (SD).
§One month postoperatively.
#Best-corrected visual acuity using the BAT.
significant only at the first postoperative month in our study. Shimizu et al 20 observed a reduction in CS with night vision that was still within normal range. Butun et al 21 demonstrated a significant reduction in CS in PRK-treated eyes compared with the control group.

In contrast to the previous results, Essente et al 22 reported that the mean CS values obtained in their PRK group (which corresponded to the PRK group in our study) were within normal range during all of the follow-up period except for a slight loss of CS at the highest frequencies 2 months after PRK. They also reported that CS returned to baseline levels 3 months after surgery. Sher et al 24, using the Pelli-Robson chart and the MCT 8000, found no statistically significant difference between CS before and 3 months after surgery.

**GD AFTER RK AND PRK**

Nighttime GD (measured with the MCT 8000) was significant after RK at the third and sixth postoperative months at all spatial frequencies. This effect increased with time up to the sixth month and was greater at higher spatial frequencies (Table 2). The latter observation is difficult to explain because the scars become less dense by the sixth month. The statistically nonsignificant decrease in CS under the effect of a central glare source at the first postoperative month correlates well with the results of Olsen and Anderson, 13 who found that, using the MCT 8000 with the central glare source on, RK did not significantly reduce CS function 1 month after surgery. No daytime GD was detected after RK using the BAT. This is consistent with results of the PERK Study, in which no effect of glare on visual acuity was found 1 year after RK. 11 After PRK, significant nighttime GD was demonstrated with the MCT 8000 at the first postoperative month at all spatial frequencies. This effect seems to persist with time at lower spatial frequencies, but there was a trend toward recovery of CS at higher spatial frequencies (Table 2). We hypothesize that an irregular corneal surface causes early postoperative glare after PRK. The BAT demonstrated significant daytime GD only at the first month after PRK. These results are different from those of Ambrosio et al 18 and Eiferman et al 23 who found, using the BAT, that glare did not affect visual acuity up to 6 months after PRK. Seiler et al 25 demonstrated a loss in glare vision that correlated significantly with the amount of attempted correction, with a greater loss of glare vision following higher corrections. We did not correlate the loss in visual acuity with glare with the attempted cor-

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**Percent change in contrast sensitivity after radial keratotomy (RK) and photorefractive keratectomy (PRK) using the CSV 1000, the Pelli-Robson chart, and the MCT (Multivision Contrast Tester) 8000.**
rection, as dividing the limited number of eyes with a narrow range of myopia (−2.00 to −4.00 D) would not have permitted meaningful statistical analysis.

**COMPARISON BETWEEN THE EFFECTS OF RK AND PRK ON CS**

Different results were obtained with the different devices used in this study to compare the effects of RK and PRK on CS. No significant difference was found with the CSV 1000 and the Pelli-Robson charts. The MCT 8000, on the other hand, demonstrated that PRK significantly decreased CS more than RK at all spatial frequencies at the first postoperative month only. However, this difference disappeared by the third month.

**COMPARISON BETWEEN THE EFFECTS OF RK AND PRK ON GD**

The BAT demonstrated no significant difference between the 2 procedures with respect to GD up to 6 months postoperatively. The MCT 8000 demonstrated that PRK caused significantly more nighttime GD than RK only at the first postoperative month.

**CLINICAL SIGNIFICANCE OF CS AND GD TESTING RESULTS**

The absence of a strong correlation between the results of the questionnaire and the objective CS and GD scores may allow us to conclude that any postoperative decrease in CS or increase in GD does not affect the everyday visual experience of patients. In the PERK Study, as well, no correlation was found between the CS function measured under photopic conditions and the glare index from a psychometric questionnaire 1 year after RK. 26

All postoperative mean values of CS (with and without glare) and visual acuity under the effect of glare fell between the corresponding preoperative 5th and 95th percentile values for the same patient populations. This was true for all the spatial frequencies at all postoperative visits. These data further support the conclusion that the statistically significant reduction of CS or increase in GD after RK and PRK may not be clinically significant.

The different results obtained by the devices used to measure CD illustrate the importance of standardization of CS testing parameters (eg, target type and illumination, testing distance, methods of reaching contrast threshold). Such standardization will make it more meaningful to compare the effect of different surgical procedures and different disease processes on CS. Also, it will be possible to measure the CS of normative populations and use this information to help determine the clinical relevance of CS results.

Our understanding of CS and GD after RK and PRK can be further extended by including more patients, following them up for longer periods of time, studying the role played by surrounding lighting conditions, pupillary diameter, and postoperative magnification on CS and GD, including dynamic CD testing, and correlating CS and GD scores after refractive procedures and corneal topography.

**REFERENCES**


