Differences Between Objective and Subjective Refractions After Radial Keratotomy

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ABSTRACT

BACKGROUND: In patients who are free of pathology, automatic refractions have shown close agreement with the subjective refractions. Clinical experience indicated that the normally strong relationship between subjective and subjective refraction is significantly weakened as a result of radial keratotomy.

METHODS: Seventy-two patients were refracted before and after surgery, objectively with a Humphrey Model #510 autorefractor and subjectively using a binocular refraction procedure without cycloplegia. All patients were free of ocular disease and had preoperative myopia ranging from -1.00 to -9.00 diopters as determined by the subjective spherical equivalent.

RESULTS: The results indicated that the preoperative difference between the mean spherical automatic and subjective refractions was a clinically acceptable 0.25 diopter. However, postoperatively, there was a statistically significant difference of 1.25 D with the automatic refractor determining more myopic refractions. Subsequent analysis revealed that the age of the patient had a direct bearing on this finding with patients less than 40 years of age showing more minus in the automatic refraction than patients 40 years and older.

CONCLUSIONS: The postoperative discrepancy between the two refractions may be explained by induced optical aberrations and may contribute towards the visual fluctuations experienced by radial keratotomy patients. It is postulated that the inconsistency in refractive determination is due to optical distortion since the age dependence of this effect may be related to the reduction of pupil size that occurs with aging. In the radial keratotomy patient, the practitioner is faced with a more complex and uncertain refraction that may vary according to refractive procedures used and other factors such as pupil size. (Refract Corneal Surg 1992:8:290-295.)

Radial keratotomy was introduced to the United States in the mid 1970s. To date, more than 90,000 patients have undergone the surgery.1 Studies concerning the efficacy of radial keratotomy indicate a success rate varying between 50% to 83% for patients having myopia between 2.00 and 8.00 diopters.2 Success has typically been defined as unaided visual acuity of 20/40 or better.3-5

Previously, it has been documented that individuals may experience a number of complications after radial keratotomy surgery, including difficulties with glare when driving at night, regression of the amount of myopia reduced by the surgery, foreign body sensation, and changes in visual acuity during the course of the day.3-5 The PERK study has estimated that 23% of patients who have undergone radial keratotomy experience some significant changes in their visual acuity during the course of...
the day. This visual fluctuation has been difficult to objectively quantify, particularly during the refractions of the patient.

In the normal, unoperated patients, there is a very close agreement between the objective autorefractor measurements and the subjective findings for an eye. However, it has been documented that the refractive assessments by automatic refractions can show inaccuracies when measuring eyes with pathology including keratoconus, aphakia, and lens and corneal opacities. The present study expands this to include those eyes who have undergone radial keratotomy surgery. The purpose of the present study is to substantiate empirically and quantify our impression that the normally good agreement between objective and subjective refractions changes as a result of radial keratotomy surgery.

MATERIALS AND METHODS

Seventy-two male and female patients were selected for the study of their objective and subjective refractions pre- and postoperatively. This retrospective study was restricted to patients sampled from the total number of radial keratotomies performed over a 6-month period dating from January 1987 to June 1987. Patients included in the study consisted of those whose eyes were free of ocular disease, who had myopia ranging from -1.00 to -9.00 D as determined by the subjective spherical equivalent, who had radial keratotomy performed on both eyes, and who had no reoperations on either eye. The age of the patients ranged from 20 to 66 years (mean, 35.56; SD, 9.17). Written permission for the use of patient data was obtained in the consent for the surgery that each patient completed.

The surgery was performed by one ophthalmologist (W.D.C.) who followed the same surgical protocol for all subjects. All patients were given a 4 cc peribulbar injection of anesthesia (50% mixture of 2% Xylocaine and 0.75% Marcaine) preoperatively. The blade depth was calibrated to 105% of the central corneal thickness. A Thornton ring was used to stabilize the eye. The incisions were performed using a thin diamond blade traced from the optical zone to the limbus. The number of incisions and optical zone size were based on the patients age and refractive correction using the prospective nomogram developed from information on 10,000 cases performed by the surgeon. Incisions ranged from 4 to 16 cuts (mean, 10.42; SD, 4.16) and optical zone size varied from 3 to 5.5 mm (mean, 3.29; SD, 0.65).

The second eye was operated on approximately 3 months after the first eye. All refractions were performed on the same day at least 3 months, but not longer than 1.5 years, after surgery had been completed in both eyes.

The sphero-cylinder refraction was performed by one of two optometrists using identical binocular refraction procedures. The distance to the chart in the refracting room was 4 m. Most studies, including PERK, have relied upon a cycloplegic refraction to determine the residual refractive correction following the surgery. Our clinical impression is, however, that the radial keratotomy patients suffer from a potential refractive inaccuracy which may not be evident in the cycloplegic eye. As an alternative to cycloplegia, we have been using a binocular refractive fogging procedure based on the principles of cyclodinamia. The comparability of these two procedures has been discussed previously and is borne out by our preoperative refractions in this study. This refraction method involved maintaining a blur of at least 1.00 D of plus power over both eyes. If the patient could still discern the 20/20 letters on four lines of a projected Snellen chart, additional plus power was added until the letters could not be read. The plus power was then gradually reduced over one eye until the patient was able to read the letters. From this point, a standard refraction was performed with emphasis on sphere, cylinder, and cylinder axis determination. At the completion, the refracted eye was again blurred by 1.00 D of plus and the identical procedure carried out on the contralateral eye. This technique allowed the examiner the ability to control accommodative responses and facilitate the most plus refraction the patient would accept without blurring of vision.

A Humphrey Automatic Refractor Model #510 was used to obtain the objective refraction. This autorefractor uses a knife-edge principle with an infrared beam and sphero-cylindrical optics to neutralize the optical error of the eye and thus determine the refractive correction. It has shown excellent reliability in the determination of refractive error. The automatic refractor also has the ability to track the eye during its refractive measurement process so that optimal alignment along the visual axis can be maintained throughout the refraction. In addition, the patient’s preoperative keratometer readings, age, and number of surgical incisions were included for statistical analysis of the data. A Humphrey Auto-Keratometer Model #410 was used for the determination of corneal curvature measurements.

RESULTS

Overall, for 64 of the 72 patients, the spherical component of the refraction showed more minus by the autorefraction relative to the subjective refraction in both eyes postoperatively. Of the eight remaining patients, all of whom were 40 years of age and older, only one patient showed more plus in both eyes by the autorefraction relative to the subjective refraction. With a 0.50-diopter difference between refractions as a criterion for a clinically meaningful difference, the autorefractor yielded a clinically sig-
nificant more minus correction in both eyes of 60 patients with the largest postoperative refractive difference being 4.25 D.

For the spherical component of the refractive correction, the difference between the mean automatic and mean subjective refractions for both eyes of the 72 patients was 0.22 D preoperatively (−4.56 vs −4.34, respectively), and 1.30 D postoperatively (−1.43 vs −0.13, respectively). In contrast, for the cylindrical component of the refractive error, there was effectively no change in the difference between the mean automatic and the mean subjective refractions; 0.13 D preoperatively (−1.05 vs −0.92) and 0.16 D postoperatively (−0.88 vs −0.72, respectively).

To corroborate statistically the change in the difference between the two refractions pre- and postoperatively, the refractions were analyzed using a mixed-model Analysis of Variance. In this analysis of the change, we also evaluated whether the age and preoperative corneal curvature of the patient were associated factors. The 72 patients were divided into two groups—those 40 years of age and older were compared to those under 40 years old. Each age group was further subdivided into two more groups according to corneal curvature—those with mean corneal curvatures of 41.50 D and greater were compared to those with curvatures less than 41.50 D. Because preliminary analysis indicated that the spherical and cylindrical corrections were independent, these two components were analyzed separately with univariate analysis of variance.

For the spherical component, the analysis of variance indicated that while there was a statistically significant difference between the refractions pre- and postoperatively, the actual magnitude of this difference was dependent on the age grouping (F[1, 68] = 13.25, P < .001). This analysis also indicated that the magnitude of the difference did not depend on the categorization of the patients by corneal curvature, nor was the difference dependent on which of the patient's eyes was being analyzed, right eye or left eye. The mean spherical refractions, by age group, are shown in the Table for the left eye only. An additional analysis of variance, undertaken to evaluate whether the number of surgical incisions was associated with the pre- and postoperative difference in refraction—those with 12 or more corneal incisions were compared to those with less than 12 incisions—revealed no statistical significance. (Due to limitations in sample size, ie, too few patients over 40 years old with 12 incisions or more, only the under-40 group was evaluated on this potential factor.)

For the cylindrical component, the analysis failed to reveal a statistically significant pre- vs postoperative change in the difference between the mean refractions yielded by the two procedures. The mean cylindrical refractions for the left eye, by age group, are also shown in the Table.

Further, linear regression analyses were conducted to consider other ways the agreement between the two refractions might have been affected by the radial keratotomy surgery. Plots showing the refractions yielded by the two procedures for each patient are shown in the Figure. As indicated by the results of the analysis of variance, separate plots are used for patients less than 40 years old (Figure) and for those 40 years of age and older (Figure). Data from the left eye only are presented because the analysis of variance indicated that there was no statistical difference between the left and right eyes, and because the two sets of plots provide virtually identical information. The important new information provided by these plots is how well the linear regression lines fit the refractions yielded by the two procedures. This goodness of fit is indicated visually by lack of scatter about the line, and is gauged.
PREOPERATIVE

UNDER 40

\[ y = 0.07 + 1.08x \]
\[ r^2 = 0.95 \]

A.

POSTOPERATIVE

UNDER 40

\[ y = -1.49 + 1.04x \]
\[ r^2 = 0.84 \]

B.

40 & OVER

\[ y = 0.28 + 1.13x \]
\[ r^2 = 0.97 \]

C.

\[ y = -0.79 + 0.86x \]
\[ r^2 = 0.79 \]

D.

FIGURE: The relationship between the spherical automatic and subjective refractions pre- and postoperatively for each of two age groups is shown. Dashed lines indicate perfect agreement between the two measures. A data point below the dashed line indicates that the autorefraction was more minus than the subjective refraction. The solid lines are the best fit (least-squares criterion) linear regression lines. The regression equations and \( r^2 \) values for each plot are indicated in the upper left portion of each frame.

There is very little scatter about the line in the preoperative refractions in both age groups, indicating a very high degree of predictability of one refraction from the other. However, the scatter about the lines increases for both age groups postoperatively, and the smaller \( r^2 \) values quantitatively mirror this occurrence. The increase in the scatter about the line postoperatively suggests the possibility that, in addition to the average "more minus" refraction provided by the autorefractor postoperatively, one or perhaps both of the refractive procedures has become less reliable with the surgery.

DISCUSSION

Preoperatively, the differences between the objective and subjective mean spherical refractions were very small and were not statistically significant.
Postoperatively, the difference between the objective and subjective mean spherical refractions was statistically significant and clinically very meaningful. This disagreement between the automatic and subjective refractions in radial keratotomy patients has not been reported previously. What has changed in the eye that would cause such a dramatic difference in the refractions between the pre- and postoperative states?

**Optical Factor**

It is plausible that adverse changes in the optical aberrations are sufficiently large to impact the optical system postoperatively. The normal corneal topography is altered as a result of the surgery by creating a centrally flat and peripherally steep-flat cornea. The postoperative knee, the junction between the centrally flattened cornea and the naturally flattened periphery, represents an area of dramatic steepening when compared with the preoperative, naturally flattening slope from center to periphery. If the pupil stays within the boundary of the surgical knee, it is likely that the refractive state of the patient is determined by the central optic zone. When the pupil dilates past the knee, the patient's refractive status is complicated by the second focal point generated by the steepened periphery. This steep area would generate a point of focus in front of the retina. This reasoning suggests that the smaller the optical zone, the greater the disparity between the two refractions. Although it is difficult to assess this possibility clearly in our data—57 of the 72 patients had the same 3.0 optical zone—there was a close to statistically significant correlation in the expected direction between optical zone size and refractive error difference in the remaining 15 patients (Pearson $r = 0.44, P < 0.10$, two-tailed test).

**Instrument Factor**

An altered corneal topography can explain how the automated refractor can achieve a more minus reading. The autorefractor is programmed to read the reflected light reflex over the entire width of the pupil, much in the same manner as retinoscopy is performed. Indeed, the typical postoperative retinoscopic reflex has been described as showing a peripherally narrowed reflex in conjunction with a widened central reflex. It is possible to have a neutral retinoscopic reflex in the optical zone portion of the cornea, yet show against motion for the same reflex in the periphery. The automatic refractor is not designed to read this unusual reflex that the postoperative radial keratotomy patient typically manifests (personal communication with technical staff, Allergan Humphrey, September 11, 1991). Therefore, it cannot resolve possibly conflicting central and peripheral retinoscopic reflexes. Indeed, the reading from the autorefractor may be more influenced by the contribution of the retinoscopic reflex from the peripheral cornea than the central cornea.

**Age Factor**

Even though the subjective and objective corrections before surgery were virtually identical, the difference between the over- and under-40 age groups might suggest that an accommodative factor influenced the postoperative refractions. The protocol for the refractions did not change postoperatively and, therefore, any change in the accommodative system during either type of refraction must have been surgically induced. The surgery did not involve the ciliary muscle, but its intended and unintended optical effects may have allowed changes in the accommodative apparatus to impact on the refractive measurements. Unlike cycloplegia, the fogging technique employed in this study does not cause the complete elimination of the accommodative reflex. Thus, accommodation could have been a factor in both the automatic and the subjective refraction.

Unlike earlier studies reporting on the refraction of the post-radial keratotomy cornea, our protocol did not include a cycloplegic refraction for the reason of providing the most natural viewing condition. In addition, routine refractions are traditionally performed without cycloplegia. Previous studies comparing the routine refractive corrections for unoperated eyes have shown little difference between the subjective and cycloplegic subjective refractions for myopes and among automatic, subjective, and cycloplegic refractions for myopes. Furthermore, since our data show nearly perfect agreement between the preoperative automatic and subjective refractions, the postoperative disagreement cannot be simply dismissed as an artifact of our method of subjective refraction. Indeed, we argue that the difference in refractive approach between this study and others was an important factor in establishing the disagreement between the subjective and subjective refraction after radial keratotomy surgery. While future studies comparing cycloplegic with noncycloplegic refractions after radial keratotomy would be helpful in determining whether accommodation during the refractions of the postoperative eyes is affected by the surgery, the fact that the most-plus subjective refraction is correct suggests that the fogging technique is not adversely affected by the surgery.

If one accepts the fact that the autorefractor overestimates the patient, why is the magnitude of the disruptive effect of radial keratotomy on the determination of the refractive correction greater in younger patients? This finding may be due to the fact that the younger patients had a slightly larger pupil than the older patients and, thus, allowed a greater influence of the postoperative knee on the automatic refractor.
readings. Although we did not measure pupil size in the present study, Loewenfeld's data on the variation in pupil diameter with age suggests that our younger patients, on average, would be expected to have larger pupils by approximately 0.50 mm. We have already discussed how the automatic refractor determines the refractive correction by measuring over the entire retinal reflex from pupil border to pupil border. A larger pupil would allow the autorefractor to sample over a greater corneal area, and thus would be more likely to be influenced by the altered postoperative shape of the cornea.

The anterior surface of the eye accounts for 67% of the total ocular refraction. Radial keratotomy, by design, drastically alters this finely-tuned optical surface by reducing the power of the cornea. The optical consequences of radial keratotomy have not been fully evaluated. Differences between automatic and subjective refractions indicate that difficulty in determining a refractive endpoint for a patient is a consequence of radial keratotomy surgery; this finding could help explain visual problems experienced by radial keratotomy patients. The knowledge of a mechanism of refractive variation in patients after radial keratotomy surgery may be helpful in understanding the fluctuations in visual acuity often experienced by these patients, and when assessing the refraction in these patients. Our results have indicated that there is an alteration in the relationship between the subjective and objective refraction of the eye in patients who have undergone radial keratotomy surgery. Further research would be required to determine exactly what factors are concerned and how these might relate to the postoperative problems in patient's vision. In the meantime, practitioners should be aware of the existence of optical deficiencies of the radial keratotomy eye and accept that a refraction is more complex and possibly less accurate, especially if based solely on the auto-refractor results. Furthermore, the surgery may have affected the reliability of one or both of the procedures for refraction.

With the discrepancy between refractions postoperatively, the clinician is faced with the dilemma of which refraction to accept as being more accurate, the automatic or the subjective. According to the philosophy of prescribing the most plus without the blurring of vision, the subjective refraction is the more accurate measurement.

REFERENCES