Explanation for Good Visual Acuity in Uncorrected Residual Hyperopia and Presbyopia after Radial Keratotomy

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It has been observed that, after radial keratotomy (RK), uncorrected residual hyperopes may have better visual acuity than expected and that some presbyopes, corrected only for distance, have adequate near-vision. We offer a possible explanation for these observations by showing that the increased spherical aberration after RK may produce a second focus 1.5 diopters or more in front of the principal focus of the eye. Invest Ophthalmol Vis Sci 31:1644-1646, 1990

It has been reported that, after radial keratotomy (RK), patients often have better uncorrected visual acuity than would be anticipated from the magnitude of the residual refractive error. This applies to residual myopia (undercorrection), the more common occurrence, and to hyperopia (overcorrection). Several explanations have been offered for this phenomenon.

Santos et al1 performed refractions after cycloplegia but measured visual acuities with normal pupil sizes. They suggest that for the case of undercorrection (myopic residual error), the good visual acuity may be the result of increased curvature of the post-RK cornea in the paracentral and peripheral regions compared to that of the central cornea. Therefore, cycloplegia may yield more myopia than would have been found without its administration.

Another explanation has been offered by McDonnell et al.2 Computerized corneal topographic mapping has identified “multifocal” corneas in some post-RK eyes. In one reported case, the optical zone of the cornea contained two distinct regions, differing in power by about 2 diopters, with the region of lower power similar in configuration to the crescent segment of a bifocal spectacle lens.

Materials and Methods. The observations of the current study have implications in cases of overcorrection (hyperopic residual error) and presbyopia. The RK procedure often results in flattening of the central cornea, the peripheral cornea being little affected.3 In most cases this produces a substantial increase in the positive longitudinal spherical aberration (LSA) of the cornea and almost certainly of the eye as a whole. Off-axis aberrations, such as coma, also may sharply increase. The effect of RK on spherical aberration is illustrated in Figure 1. Photokeratoscopic data are shown for a particular post-RK eye in Figure 2. It is quite evident from these data that dioptric power increases substantially as one moves from the center of the cornea to the periphery.

In a previous communication we outlined a method for estimating LSA and image contrast for pre- and post-RK corneas.4 Specifically, using photokeratoscopic data, we estimated corneal sagittas for a series of semi-chord lengths, and then used this data to find a sixth-order polynomial surface of revolution approximating the corneal shape. It then was easy to estimate LSA for any pupil size. For example, for the data shown in Figure 2 we estimate the LSA to be approximately 2 diopters at the edge of a 6-mm pupil.

We show that under appropriate conditions, this
Fig. 2. Photokeratoscopic results for the post-RK cornea of patient CW. Dioptic powers are given at eight positions around each of nine rings. The largest ring has a radius of approximately 4 mm. The first ring is about 0.8 mm from the center, and the other rings are separated by about 0.4 mm. It is quite evident from the figure that power increases from the center to the periphery, so LSA is greater for this cornea than, for example, a spherical cornea.

amount of spherical aberration makes the cornea "bifocal"; ie, a second well-defined focus occurs approximately 1.5 diopters inside the paraxial focus.

The assumptions inherent in the calculations of Figures 3 and 4 are that aberrations affecting central vision, other than LSA, are negligible, and that any cylindrical error is corrected with a spectacle lens. In this example we have taken the pupil diameter to be 6 mm and the LSA at the edge of the pupil to be 2.00 diopters, a magnitude close to that estimated for the post-RK photokeratoscopic data shown in Figure 2.

Results. Figure 3 shows the calculated image contrast (modulation transfer) as a function of spatial frequency when the receiving plane is placed in front of the paraxial focus by a distance of 1.5 diopters. This is the approximate position of the second focus of the system. It should be noted that two ranges of intermediate spatial frequencies around 10 and 20 cyc/deg are missing from this image but that other spatial frequencies are represented. Moreover, the modulation transfer function never takes on negative values, so spurious resolution can not occur. Figure 4 shows image contrast as a function of the distance in diopters (amount of defocus) of the receiving plane in

Fig. 3. The modulation transfer function, image contrast/object contrast vs spatial frequency, for a model eye with 2.00 diopters of positive longitudinal spherical aberration at the edge of a 6-mm pupil. The eye has no other aberrations. The receiving plane (image plane) is 1.50 diopters in front of the paraxial focus.
Kinetics. The modulation transfer (image contrast/object contrast) as a function of defocus (distance in diopters of the receiving plane in front of the paraxial focus) for a model eye at three spatial frequencies. The eye has 2.00 diopters of positive longitudinal spherical aberration at the edge of a 6-mm pupil. It has no other aberrations.

Fig. 4. The modulation transfer (image contrast/object contrast) as a function of defocus (distance in diopters of the receiving plane in front of the paraxial focus) for a model eye at three spatial frequencies. The eye has 2.00 diopters of positive longitudinal spherical aberration at the edge of a 6-mm pupil. It has no other aberrations.

We suggest that this result is not exceptional but instead generally applicable. A larger study is required to confirm it. The amount of LSA in the calculations for Figures 3 and 4 is quite large but not unusual in post-RK corneas. Also, we have used the lowest-order approximation to this aberration (third-order theory) in order to rule out the possibility that this result is peculiar to one particular corneal shape. In this lowest approximation (third-order theory), longitudinal spherical aberration is proportional to the half-diameter of the pupil squared. This is equivalent to $Y^2$ in Figure 1. The term "third-order theory" is usually adopted because in the general treatment of spherical aberration it is the transverse form that is considered. Transverse spherical aberration is proportional to the half-diameter of the pupil cubed. However, in our treatment we used the related, but simpler, longitudinal spherical aberration. In any real cornea the terms in the LSA would be higher (and other aberrations will be present), but we believe that they would have little effect on the result. The result, however, depends on pupil diameter. It is noteworthy that our calculations suggest that this effect persists for smaller pupils although it becomes less pronounced.

When surgery produces a more extreme change in corneal curvature from center to periphery, a "mid-peripheral knee" may be produced. In these cases, higher-order terms in LSA would become more important. A calculation of bifocal effects in such cases must include consideration of these higher terms. We expect these higher terms to have little effect on our results.

Discussion. We offer the above consideration of LSA and its effect on image contrast as a plausible explanation, in some instances, for the observation that visual acuity after overcorrected RK (residual hyperopia) is often better than expected. This may also explain adequate near-vision in presbyopes corrected only for distance after the surgical procedure.

Key words: radial keratotomy, spherical aberration, vision correction

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