CLINICAL INVESTIGATION

The Refractive Changes and Long-Term (3 Years) Results of Radial Keratotomy Performed at High Altitude

Tekin Yaşar*, Şaban Şimşek* and Ömer Faruk Yılmaz†

*Department of Ophthalmology, Faculty of Medicine, The University of Yüzüncü Yıl, Van, Turkey; †Beyoğlu State Hospital, Chief of Ophthalmology Clinic, Istanbul, Turkey

Purpose: To evaluate the development of regression or progression following radial keratotomy (RK) performed at high altitude (1,720 meters) at long-term follow-up (3 years).

Methods: Thirty-nine eyes of 21 myopia patients (between −3.25 D and −11.00 D) whose ages were 19–32 years were included in the study. The RK procedures were performed in standard Russian style.

Results: The average spherical equivalent cycloplegic refractions were −5.49 D ± 2.08 (SD) preoperatively, −1.64 ± 1.59 D in the short-term (3.41 ± 1.46 months) and −1.40 ± 1.71 D in the long-term (30.72 ± 4.36 months) follow-up period. There was no statistically significant difference between these values at the short- and long-term follow-up measurements ($t = -1.57$, $P = .12$).

Conclusions: The refractive changes following RK performed at high altitude occur through a combination of both the direct effect of reduced barometric pressure and the edematous corneal expansion because of hypoxia. An ophthalmologist performing RK surgery at high altitude must consider the long-lasting therapeutic effects of high altitude surgery compared to surgery at sea level. **Jpn J Ophthalmol 2001;45:156–159** © 2001 Japanese Ophthalmological Society

Key Words: High altitude surgery, radial keratotomy.

Introduction

Radial keratotomy (RK) has an important place in myopia surgery because of its well-known characteristics (reliability, cheap and easy performance, no necessity for highly technical equipment, etc.) despite the great advances in refractive surgery. Radial keratotomy is preferred to photorefractive keratectomy (PRK), laser-assisted in situ keratomileusis (LASIK) and other myopia surgery, especially in high corneal astigmatism and postoperative astigmatism following cataract surgery.[1–5] Rowsey and Morley[6] suggested that RK would always have a place in the treatment of moderate myopia. We believe that it is a matter of scientific ethics to report long-term results on patients even if the technique is not commonly used today.

There are few reports about the effects of high altitude on RK and about possible etiologic explanations.[7–11] In our previous study we reported a hyperopic shift induced by altitude following RK using two groups (at sea level and at 1,720 meters).[11] In another study, we reported almost the same results in matched cases according to sex, age, degree of myopia, number of incisions, and optic zone size at short-term follow up.[12] However, there is no study in the literature about the long-term results of RK performed at high altitude. In this study of RK performed at high altitude with long-term follow-up, the development of regression or progression was evaluated, and in the light of these findings, the etiology

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Correspondence and reprint requests to: Tekin YAŞAR AR, MD, Department of Ophthalmology, Faculty of Medicine, The University of Yüzüncü Yıl, Van 65300, Turkey

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of the changes that occurred at high altitude was discussed.

Materials and Methods

Thirty-nine eyes of 21 myopia patients (minimum, −3.25 D, maximum, −11.0 D, mean = −5.49 D ± 2.08 SD), 8 women and 13 men between the ages of 19 and 32 years (mean: 24.76 ± 3.92 years) who had undergone RK earlier in our clinic (Van University Hospital, at an altitude of 1,720 meters) were included in the study. Mean preoperative spherical equivalent cycloplegic refraction was −5.49 ± 2.08 D.

Inclusion criteria, examination methods and surgical procedure were explained in our previous study in detail.[11] All subjects were informed about the procedure, the possible complications, and what expectations the subject should have. All operations were performed by the same surgeon (ÖFY) using the same techniques (Russian style, 8–12 incisions, 3–3.2 mm optic zone). Determinations of optic zone size and incision number were based on many factors, such as the degree of desired correction, age, sex, refraction and keratometric values, intraocular pressure (IOP), axial length, corneal topography, and prior experience of the surgeon. Surgery was performed under topical anesthesia using an operating microscope. While the patient was looking at the light of the microscope an incision was made on the corneal epithelium using special markers. A Russian diamond blade was extended to 100% of the thinnest 3-mm paracentral corneal measurement. Standard Russian technique incisions were initiated by plunging the blade into the stroma and extending the blade in centripetal fashion no closer than 1 mm from the corneoscleral limbus. Eight incisions were made on the eyes from −3.00 to −4.50 D, 10 incisions from −4.50 to −6.00 D, and 12 incisions over −6.00 D to alter the central corneal optic zone size. Then the eyes were instilled with 0.3% tobramycin sulphate and covered with a patch for 24 hours. Postoperatively topical 1% prednisolone acetate (four times a day, 5–15 days) and 0.3% tobramycin sulphate (four times a day, 5 days) were used.

The surgeon examined the patients on the first postoperative day and then at 3 days, 10 days, 1 month, 3 months, 6 months, 1 year, 2 years, and 3 years later. Short-term follow-up time (3 months) was 3.41 ± 1.46 months (mean; range, 2–6 months), and long-term follow-up time (3 years) was 30.72 ± 4.36 months (mean; range, 24–38 months).

The results were analyzed using a Minitab computer program. Comparisons were made using paired Samples Student *t*-tests ($P < .05$ significant).

Results

Mean IOP was 16.35 ± 2.31 mm Hg preoperatively, 16.00 ± 1.98 mm Hg at the 3-month follow-up and 15.94 ± 1.94 mm Hg at the 3-year follow-up examinations. There were no statistically significant differences between preoperative and short-term follow-up IOPs ($P = .354$, $t = 0.94$), between preoperative and long-term follow-up IOPs ($P = .234$, $t = 1.21$) and between short-term and long-term follow-up IOPs ($P = .160$, $t = 1.43$).

Spherical equivalent cyclopegic refraction values were −1.64 ± 1.59 D in short-term follow-up and −1.40 ± 1.71 D in long-term follow-up (Figure 1). There was no statistically significant difference between these two values ($t = -1.57$, $P = .12$).

Discussion

Several studies have reported that hyperopic shift and much more corneal flattening occur in RK eyes at higher altitudes than at sea level.[7–12] To our knowledge, there is no study in the literature about long-term follow-up results.

Synder et al reported a 1.75 D hyperopic shift and a 1.50 D corneal flattening in a subject who traveled from sea level to an altitude of 9,000 feet, and suggested that these changes might have been caused by the direct effect of the decreased barometric pressure.[7] White and Mader documented a 1.00 D hyperopic shift and a 1.00 D corneal flattening at 10,000 feet, and the refractions returned to normal when the patient moved back to the sea level.[8,13] The authors hypothesized that hyperopic shift resulted

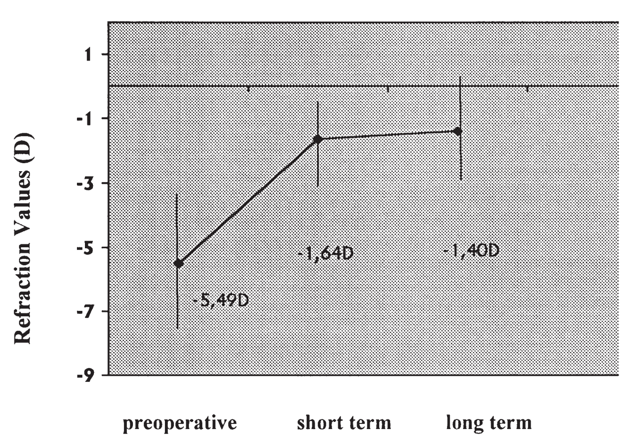

Figure 1. Average spherical equivalent cycloplegic refraction values in radial keratotomy patients operated on at high altitude. Preoperative: −5.49 ± 2.08 D. Short-term (3 months) follow-up: −1.64 ± 1.59 D. Long-term (3 years) follow-up: −1.40 ± 1.71 D.

from a metabolic process caused by the effect of corneal hypoxia in the area of RK incisions (hypoxic corneal expansion). However, these measurements were taken in subjects who stayed only 24–72 hours at this altitude following the RK procedures. They were not the results in patients who had undergone RK and lived at the same high altitude.

In our previous study, we reported short-term results on patients who had undergone RK and lived at a high altitude. Corneal flattening was much more prominent compared to results at sea level. Refractive values did not show a statistically significant difference between the postoperative 10th day and 3rd month measurements.[11] In this study we evaluated long-term follow-up results (mean = 30.72 ± 4.36 months; range, 24–38 months) of 39 eyes of 21 patients who were included in our earlier study. We were able to follow these groups of patients regularly for an extended period because they were mostly hospital staff. Refractive results for these patients were not statistically different between the examinations at 3.41 and 30.72 months.

It is reported that keratometric results remained the same for the first 6 hours[9,14] in patients who moved to a high altitude following RK at sea level. The authors suggested that if hyperopic shift was due only to barometric pressure, it should have shown a difference immediately. The same authors suggested that corneal flattening resulted from reduced corneal metabolic process, which occurs around RK incisions following stromal edema. Winkle et al[15] supported the hypoxic theory because they found significant pachimetric thickening and corneal flattening with hyperopic shift in their 20 RK patients kept in a normobaric anoxic enviroment. Also, they suggested that the relative hypoxia under the lids was the cause of the hyperopic shift seen in the morning.

Schanzlin et al[16] suggested radial corneal incisions permanently weaken the perpendicular stromal fibrils between the incisions.

In the light of these findings it is not possible to discard any of these theories. Although Mader and White[8] and Ng et al[9] reported that there were not any keratometric changes in the first 6 hours in RK patients who moved to a high altitude, the study of Kemp et al,[17] which showed IOP had caused diurnal fluctuations in the visual acuity of RK patients supports Synder et al's[7] hypothesis of the direct effect of barometric pressure. These results also support the results of our previous study which showed −0.50, −2.4, and −3.5 D (more improvement in high myopia) more improvement at high altitude compared to measurements at sea level.[11] These effects will occur more easily in the weak corneal fibril area caused by the RK incisions, as shown by the Schanzlin et al study.[16]

In our previous study, refractive values did not show a statistically significant difference between the postoperative 10th day and 3rd month measurements.[11] In the current study there was no statistically significant difference between refractive values of the 3-month and the 3-year follow-up and there was slightly more flattening at the long-term follow-up. If the hypoxic theory was the only factor in these changes, hyperopic shift must have regressed after corneal stromal edema was resolved, as in White and Mader's study,[13] which reported hyperopic shift regression after returning to sea level. Mauger and Hill[18] and Tompach et al[19] reported that the decreased corneal tissue oxygen level caused significant delays in healing. We suggest that hypoxia has a role in hyperopic shift at high altitude because of the hypoxic corneal expansion effect and that hypoxia also delays wound healing.

In the light of these findings, we suggest that the etiology of RK changes performed at high altitude is a combination of disturbed IOP balance because of the reduced barometric pressure, weakened corneal stromal fibrils around RK incisions, and edema due to hypoxia and its additive effect in delaying wound healing.

In conclusion, RK is more effective when performed at high altitutde than at sea level. Regression or progression is not seen. An ophthalmologist performing RK surgery at high altitude must consider this additive therapeutic effect, which does not change with time. Ophthalmologists must consider redesigning their RK nomograms.

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