The Effect of Altitude on Radial Keratotomy

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Abstract: The authors analyzed refractive results of patients who underwent radial keratotomy (RK) at sea level and high altitude and evaluated the effects of the altitude. A total of 102 eyes undergoing RK procedures performed in two clinical centers having different altitude were analyzed. The results compared between subjects who had undergone RK at sea level (İstanbul/Turkey) and at an altitude of 5750 feet (Van/Turkey) were compared. Subjects were 19–42 years old with myopia from −4.00 to −12.00 diopters (D). The average preoperative spherical equivalent cycloplegic refractions (SECR) were −8.01 ± 1.86 D and −6.99 ± 2.15 D in the İstanbul and Van groups, respectively. These were divided into subgroups according to myopia degree and number of incisions and optic zone size. The RK procedures were performed by the same surgeon with diamond blade in standard Russian style. The average changes in SECR were 5.09 ± 1.29 D and 6.50 ± 2.24 D in subjects who had undergone RK at sea level and at 5750 feet, respectively. There was a significant difference between the subgroups ($P < 0.0002$). This difference was especially higher in the high myopia subgroups. Additionally, we obtained a partial relation between increase of RK incision number and SECR change at high altitude but not at sea level. No notable regression and progression were seen in the 3 months of follow-up at high altitude. These results support hypotheses suggesting both corneal hypoxic expansion in the area of RK incisions, which may lead to central corneal flattening, and barometric pressure directly altering corneal shape, which is responsible for the hyperopic shift induced by altitude. Ophthalmologists performing RK surgery at high altitude had better consider redesigning their RK nomograms in light of these findings. However, when the nomogram used at sea level was used at high altitude, the subjects became hyperopic. **Jpn J Ophthalmol 1998;42:119–123** © 1998 Japanese Ophthalmological Society

Key Words: Altitude, radial keratotomy.

Introduction

Radial keratotomy (RK) is a commonly performed procedure for the correction of myopia. The Soviet physicians Yenaliev[1] and Fyodorov[2] developed the modern form of the procedure. Fyodorov also was the first to incorporate multiple preoperative variables in an algorithm to determine the ideal surgical parameters for an individual eye. Over the last decade, RK techniques and technology have evolved to enable a greater degree of safety and predictability. Technologic advances in instrumentation, the use of corneal topography, as well as a greater understanding of corneal biomechanics (including the influences of patient age, wound morphology, and wound healing) all have contributed to the improved level of safety, efficacy, and predictability.[3–6] Predictability is the most important problem in RK procedures. Most surgeons believe that the efficacy of RK is related to incision number, incision depth, corneal refractive power, optic zone (OZ) size, age, gender, intraocular pressure (IOP), axial length, tissue factors affecting wound healing, and some other unknown factors.[3,4,6–9] However, these criteria have yet to be firmly established in RK formulation. Altitude should also be considered as a criterion for predictability in RK procedures. Five reports have described hyperopic shifts in refractive error in patients who have had RK after brief exposure to increased altitude, but no report has adequately described subjects who have undergone RK and lived continuously in high altitude.[10–14] In this study, the authors

compared refractive results of patients who underwent RK at sea level and high altitude. The effects of altitude are discussed later.

Subjects and Methods

One hundred two eyes of 51 patients who had undergone RK in two different clinical centers were analyzed and results between the center at sea level (İstanbul/52 eyes: 9 men, 17 women) and the center at an altitude of 5750 feet (Van/50 eyes; 11 men, 14 women) were compared. All subjects were informed about the procedure in detail, the possible complications, and what expectations the subject should have. They were all healthy adults not taking any medications. The average age was 29.88 ± 8.33 years (range 19–42 years) in İstanbul and 27.66 ± 6.30 years (range 19–38 years) in Van. The subjects had preoperative spherical equivalent cycloplegic refractions (SECR) ranging from -4.00 to -13.50 diopters (D) (-8.01 ± 1.86 D) in İstanbul and from -4.00 to -13.00 D (-6.15 ± 2.57 D) in Van. Both groups were divided according to SECR into three subgroups, which were from -4.00 to -6.00 D, from -6.25 to -8.00 D, and over -8.25 D. Additionally, the subjects were evaluated according to the number of incisions and OZ sizes (Table 1). All operations were performed by the same surgeon (OFY) at different times.

Measured manifest and cycloplegic refraction (achieved with cyclopentolate 1%), keratometry reading (using Javal's ophthalmometer), ultrasonic biometry, applanation tonometry, and central-peripheral corneal pachymetry were determined in all subjects. All measurements were done in the afternoon to prevent the added hypoxia effect of lid closure during sleep. Determination of OZ size and incision number were based on many factors such as the degree of desired correction, age, gender, refraction and keratometric values, IOP, axial length, corneal topography, and prior experiences of the surgeon. Surgery was performed with a miotic pupil under topical anesthesia and coaxial operation microscope. The surgeon marked the central visual axis by getting the subject to look at the light of the operation microscope, and an incision fashion 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 extended centripetal fashion no closer than 1 mm from the corneoscleral limbus. The surgeon made 8, 10, or 12 radial incisions from the limbus to the OZ. 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 OZ size. A second deepening incision, when indicated, was performed in the same incision groove stopping no closer than 7 mm from the central corneal OZ. The surgeon then irrigated the eyes with balanced salt solution using a 27-gauge cannula. Then the eyes were instilled with 0.3% tobramycin sulphate and covered with a patch for 24 hours. Postoperative medical therapy included a 5-day regimen of topical steroid (1% prednisolone acetate), prophylactic antibiotics (0.3% tobramycin sulphate), and artificial tears instilled four times daily, followed by 3 days of twice-daily instillation. When SECR was greater than $+1.00$ D within the first postoperative week, steroid was stopped and topical 0.25% timolol maleate and dekspanthenol ophthalmic pomade were used for as long as necessary.

The surgeon examined the patients on the first postoperative day and then 3 days, 10 days, 1 month, 3 months, 6 months, and 1 year later. We evaluated the 10-day and 3-month values of the patients because of the shorter follow-up time in the Van group. Each postoperative visit included all the examinations performed preoperatively. The average postoperative follow-up time was 10.2 ± 4.3 and 3.3 ± 2.7 months in the İstanbul and Van groups, respectively.

The results were analyzed using the Minitab computer program. Comparisons were made using either nonpaired or paired samples Student's t tests, Wilcoxon signed-rank test, and chi-square tests as appropriate ($P < 0.05$ was considered significant).

Results

No statistically significant difference was found between genders in the two groups ($P > 0.34$). The average preoperative SECRs for the İstanbul and Van groups, respectively, were -8.01 ± 1.86 D and -6.99 ± 2.15 D, and postoperative SECRs were -2.97 ± 1.71 D and -0.31 ± 0.68 D.

The average refraction changes and preoperative SECRs of the subgroups were 4.30 ± 0.78 D and -4.81 ± 1.24 D in the subgroup from -4.00 to -6.00 D; 4.70 ± 1.14 D and -7.16 ± 0.50 D in the subgroup from -6.25 to -8.00 D; and 5.63 ± 1.21 D and -9.11 ± 1.54 D in the subgroup over -8.25 D in the İstanbul and Van groups, respectively (see Table 2 and Figure 1). The differences between the average refraction changes in the İstanbul and Van groups were statistically significant regarding the -6.25 to -8.00 D and the over -8.25 D subgroups ($P <$

Table 1. Refractive Results Obtained With the Same Number of Radial Keratotomy Incisions and Optic Zone Sizes

	Radial Keratotomy/Optic Zone Size[a]				
	8/3.2	10/3.2	10/3.0	12/3.2	12/3.0
Number					
İstanbul	—	7	29	—	16
Van	6	21	—	8	15
Age					
İstanbul	—	30.43 ± 7.39	29.01 ± 9.31	—	30.00 ± 7.16
Van	25.01 ± 4.98	27.05 ± 6.48	—	31.62 ± 6.44	27.47 ± 6.08
Spherical equivalent					
Preoperative					
İstanbul	—	−5.42 ± 1.50	−8.01 ± 1.64	—	−9.14 ± 1.19
Van	−4.25 ± 0.22	−5.92 ± 1.25	—	−7.68 ± 1.06	−9.00 ± 1.73
Postoperative					
İstanbul	—	−1.57 ± 1.67	−2.93 ± 1.74	—	−3.65 ± 1.31
Van	−0.33 ± 0.64	−0.40 ± 0.63	—	0.12 ± 11.15	−0.41 ± 0.35
Change					
İstanbul	—	3.60 ± 0.57	5.06 ± 1.37	—	5.65 ± 1.00
Van	4.04 ± 0.60	5.52 ± 1.30	—	7.81 ± 0.25	8.72 ± 1.84

[a]Number of incisions/optic zone size.

0.0001); differences were not significant, however, in the −4.00 to −6.00 D subgroup ($P > 0.05$).

The average SECR changes were 4.04 ± 0.60 D in the eyes with 8 RK/3.2 mm OZ, 5.52 ± 1.30 D in the eyes with 10 RK/3.2 mm OZ, and 7.81 ± 0.25 D in the eyes with 12 RK/3.2 mm OZ in Van. The difference between the groups was significant ($P < 0.001$ and $P < 0.0001$). The average SECR changes were 5.06 ± 1.37 D in the 10 RK/3.0 mm OZ subgroup and 5.65 ± 1.00 D in the 12 RK/3.0 mm OZ subgroup in İstanbul. There was no significant difference between the groups ($P > 0.05$) (Figure 2). Refractive results obtained with the same number of RK incisions and OZ size are displayed in Table 2.
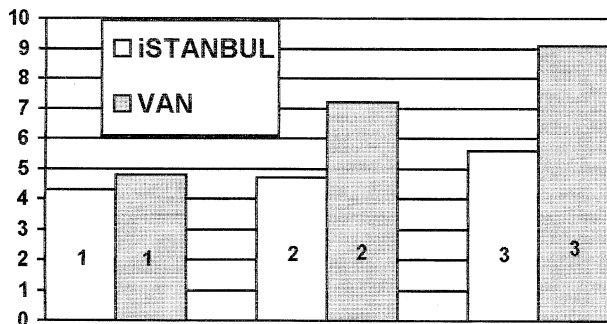
The average SECR was −0.31 ± 0.68 D and −0.56 ± 1.27 D on the 10th day and 3rd month after the operation, respectively, in the Van group. The differences between the postoperative 10-day and 3-month values were not statistically significant ($P > 0.05$).

Discussion

Although many reports have described the postoperative stability of RK, no comprehensive and long-lasting study has documented postoperative refractive changes with altitude. These studies have involved only one measurement at each altitude, mainly at sea
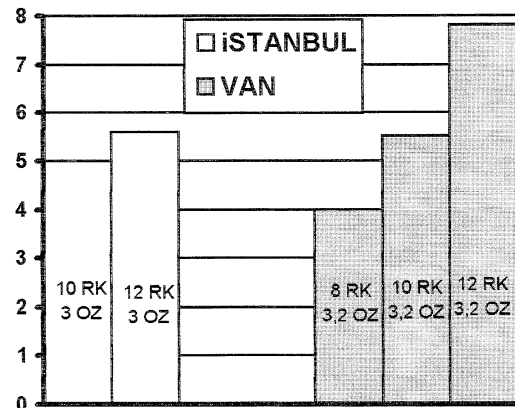

Figure 1. The changes of spherical equivalent cycloplegic refractions in subgroups. 1: −4.00 to −6.00 diopter (D) subgroup; 2: −6.25 to −8.00 D subgroup; 3: over −8.00 D subgroup.

Figure 2. The spherical equivalent cycloplegic refraction change of subgroups according to number of radical keratotomy (RK) incisions and optic zone (OZ) size (mm).

Table 2. Refractive Results in Different Myopia Degrees

	Myopia (Diopters)			
	−4.00 to −6.00	−6.25 to −8.00	−8.25 to −11.00	Total
Number				
İstanbul	9	15	28	52
Van	22	15	13	50
Age (years)				
İstanbul	28.33 ± 11.62	33.60 ± 8.71	29.77 ± 7.12	29.88 ± 8.38
Van	25.82 ± 5.75	28.53 ± 5.97	28.39 ± 6.51	27.66 ± 6.30
Spherical equivalent				
Preoperative				
İstanbul	−4.83 ± 0.70	−7.33 ± 0.51	−9.40 ± 0.82	−8.01 ± 1.86
Van	−4.95 ± 0.54	−7.66 ± 0.36	−9.65 ± 1.56	−6.99 ± 2.15
Postoperative				
İstanbul	−0.88 ± 0.85	−2.51 ± 1.34	−3.92 ± 1.33	−2.97 ± 1.71
Van	−0.12 ± 0.89	−0.50 ± 0.48	−0.46 ± 0.38	−0.31 ± 0.68
Change				
İstanbul	4.30 ± 0.78	4.70 ± 1.14	5.63 ± 1.21	5.09 ± 1.29
Van	4.81 ± 1.24	7.16 ± 0.50	9.11 ± 1.54	6.50 ± 2.24

level, on a relatively small number of subjects. No study has reported the results of patients having RK at a high altitude and remaining there. We aimed to compare the results of our subjects who had RK at 5750 feet with those at sea level to determine the effect of altitude on RK.

Hyperopic shift and corneal flattening in subjects who have had RK with exposure to increased altitude have been described. The magnitude of the hyperopic shift was progressive with increasing altitude, but it is unknown whether the hyperopic shift is progressive at the same altitude in the course of time.[10–14] 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 9000 feet. The authors did not state how long the subject was at 9000 feet before these measurements were obtained. They suggested that these changes might have been caused by the direct effect of decreased barometric pressure.[10] White and Mader[11] documented a 1.00-D hyperopic shift and a 1.00-D corneal flattening in both eyes of one subject who traveled from sea level to an altitude of 10 000 feet. The refractions returned to normal when the patient moved back to sea level. The same authors later reported an average of a 1.03 ± 0.16 D hyperopic shift and a 0.59 ± 0.19 D corneal flattening in all four eyes of two RK-treated subjects who traveled from sea level to 12 000 feet and a 1.94 ± 0.26 D hyperopic shift and a 1.75 ± 0.27 D corneal flattening when they traveled to 17 000 feet. These measurements were obtained after 48 hours of continuous exposure at these altitudes. The authors hypothesised that hyperopic shift resulted from a meta-

bolic process caused by the effect of corneal hypoxia in the area of the RK incisions.[12] They defined it as "hypoxic corneal expansion."

It is well documented that ocular oxygen tension decreases with increasing altitude and that a normal cornea exposed to zero oxygen concentration will swell approximately 7% per hour.[15,16] The normal corneal stroma is composed of a cross-hatched meshwork of collagen fibrils that provides corneal stability under both normoxic and hypoxic conditions. Radial incisions tend to damage more fibrils running perpendicular to the length of the incisions, and this may lead to a permanent decrease in corneal strength perpendicular to the direction of the incisions. The preservation of radially oriented fibrils may lead to an increase in circumferential corneal elasticity, and incisions in the Bowman layer also may predispose the cornea to expansion as a result of this layer being altered by RK incisions, which are less restrictive.[12,15] Additionally, endothelial cell damage, which may occur near RK incisions, could predispose this area to localized edema during hypoxic conditions. It is possible that even this small edema may cause a circumferential expansion and subsequent elevation of the cornea peripheral to the OZ. This annular band of corneal expansion may lead to central corneal flattening within the OZ and enhance the effect of RK.[12]

It has been reported that the number of RK incisions does not affect the refraction value linearly.[13] In contrast, our results obtained at high altitude were partially related to the increases in RK incision number. The difference between the change of SECR in İstanbul and Van was not significant in the −4.00 to

−6.00 D subgroup, which received relatively few RK incisions, whereas a notable difference was found between the −6.25 to −8.00 D and the over −8.25 D subgroups. In addition, there was a relation between increasing RK incision number and refraction increase in eyes with 8, 10, and 12 RK incisions with the same OZ (3.2 mm) in Van. The same relation was not present in the İstanbul group, which underwent different numbers of RK incisions (10 and 12), keeping the same OZ (3.0 mm). These results indicate that there is a positive relation between RK incision number and refraction increase, particularly in higher myopia groups, at altitude but not at sea level. This cannot be explained only by hypoxic expansion theory.

It has also been reported that refractive and keratometric changes at high altitude do not occur immediately; changes occur at least 24 hours later. Thus, decreased barometric pressure does not affect corneal flattening.[11–14] This necessity of extended time to produce notable hyperopic change suggests a metabolic origin, so that it may involve a slow increase in corneal hydration around the RK incisions secondary to cellular hypoxia and decreased cellular respiration. In contrast, Synder[10] assumed that decreased barometric pressure was purely responsible for changes in corneal shape at high altitude. The cornea becomes more sensitive to IOP and barometric pressure alterations, because the more the number of RK incisions increases, the greater the circumferential elasticity.[13] It is possible that the weakened cornea in RK eyes exposed to decreased barometric pressure might bow forward with the effect of IOP. The decrease of barometric pressure at high altitude is a common physical rule. On the other hand, IOP remained unchanged during exposure to high altitude or in a simulated altitude chamber.[13,14,16] Therefore, we did not evaluate these cases in the study. Mader et al[14] reported that progressive and reversible hyperopia occurred within 72 hours at high altitude, and this was correlated to keratometric and videographic alteration. In our study, in contrast, refraction increase was not progressive. The difference between the 10-day and 3-month SECR values was not significant. If central corneal flattening was due purely to corneal hypoxia, a notable myopic shift should have occurred after hydration disappeared in time.

Keratometric results were not included because post-RK keratometry readings were not meaningful due to the aspherical shape of the cornea after RK surgery.[17,18] It is not known at which altitude the hyperopic shift starts. Nonetheless, our study showed the presence of hyperopic shift, particularly in higher myopia groups, at 5750 feet.

In conclusion, ophthalmologists performing RK surgery should be aware of the higher spherical equivalent increases at high altitude and the notion that subjects might have hyperopia. They should consider redesigning their nomograms of RK in light of these findings. Because our data are only suggestive, comprehensive studies are needed to determine the effect of altitude on RK.

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