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Progressive hyperopic shift after radial keratotomy: possible causes

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Aim — to describe possible causes of progressive hyperopia in patients who underwent radial keratotomy. **Material and methods**. The study enrolled 33 subjects who underwent radial keratotomy earlier in their lives, of them 15 controls (29 eyes, group I) with no refractive error and 18 patients (35 eyes, group II) with progressive hyperopia. The number and type of keratotomy scars was determined during biomicroscopy. Biomechanical properties of the cornea were assessed by means of bidirectional applanation (Ocular Response Analyzer). Dynamic contour tonometry (Pascal) was also used for intraocular pressure (IOP) measurement. Evaluation of the optic nerve head and retina included standard automated perimetry (Humphrey Field Analyzer) and confocal scanning laser ophthalmoscopy with Heidelberg Retinal Tomograph (HRT III). **Results.** Group II showed reliable signs of low corneal rigidity, namely reduction of CH and CRF values (by 2.4 and 1.6 mmHg respectively) and central corneal thickness (by 56 microns) as compared to the controls. Tonometry results differed inconsiderably showing a tendency toward hypertension in both groups. The interquartile range of IOP was 17.8÷22.4 mmHg in group II and 16.3÷20.6 mmHg in group I. Changes in retinal light sensitivity and optic nerve head parameters were more pronounced in the controls. **Conclusion.** Several reasons for lowering of corneal rigidity can be suggested: initial biomechanical parameters of the cornea, surgical interference, and age-related changes. We think that hyperopic shift results from the combination of low corneal rigidity and increased IOP, i.e. not the lamina cribrosa but the cornea becomes the target of ocular hypertension. Thus, patients with weakened corneal refraction after radial keratotomy are at risk for developing glaucoma in the late postoperative period.

Keywords*: radial keratotomy, hyperopic shift, glaucoma, biomechanics, cornea, intraocular pressure, dynamic contour tonometry.*

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Anterior radial keratotomy (RK) is a refractive surgical procedure that consists of making non-perforating anterior corneal incisions, the direction of which coincides with imaginary radii of the corneal circumference, leaving the central zone (not less than 3 mm in diameter) intact. In fact, meridional incisions would be a more appropriate name, but even so, the term 'radial keratotomy' became most accepted. In the 1970's and 80's of the last century RK was widely used for surgical correction of spherical myopia and astigmatism. It is estimated that over 1 million procedures were performed in the Unites States before 1995, while in Russia the S.N. Fyodorov "Eye Microsurgery" complex alone accounts for more than 600,000 operations performed before 2000 [1—3].

On the basis of clinical experience and analysis of published data all negative effects of refractive surgery, particularly RK, can be divided into complications in the true sense, side effects, and late effects [4—17]. Complications as they are usually understood have varying degrees of influence on the functional outcome of the surgery. They are unpredictable and, thus, undesirable. Typical intra- and postoperative complications of RK include perforation and eruption of the central cornea, coarse scarring, induced astigmatism, and reduced best corrected visual acuity (BCVA). Side effects can be observed even in complication-free patients, in whom the intended refractive correction was achieved, and include fluctuating visual acuity, impaired mesopic vision, and reduced contrast sensitivity. There are also a number of side effects (aftereffects) that can develop in the late postoperative period.

These comprise an increased susceptibility of the cornea to blunt trauma, unreliability of tonometry results, errors in intraocular lens power calculation, and — progressive hyperopia [4, 18—25].

The latter implies a refractive shift toward hyperopia and development and/or progression of corneal astigmatism. It usually manifests in patients after 45—50 years of age, whose primary post-RK refraction was close to emmetropic.

Weakening of corneal refraction following RK is known to be due to central corneal flattening (radius of curvature of the central cornea increases), which in turn results from mid-peripheral corneal steeping (radius of curvature of the mid-peripheral cornea decreases) under intraocular pressure (IOP). The effect of refractive surgery is individual and, other things being equal, depends on the depth of incisions, diameter of the central (intact) zone, and, to a lesser extent, number of incisions. The maximum refractive effect is achieved with 4—8 anterior radial incisions to the level of Descemet's membrane leaving a Ø 3 mm central zone.

Thus, the major contributors to corneal flattening following RK are the incisions themselves, intraocular pressure, and biomechanical parameters of the cornea at baseline (particularly, its resistance to deformation under load — rigidity, that is).

Making of anterior non-perforating non-limbal incisions causes a decrease of destruction threshold as well as the extent of corneal deformation under a destructive load in experiment [4, 26].

Clinical signs of reduced corneal rigidity following RK include fluctuating visual acuity, increased susceptibility of the cornea to blunt trauma, risk of keratotomy scars rupture during phacoemulsification cataract surgery, and a rather strong dependence of the refractive outcome on the type of corneal healing. The target refraction is usually achieved in so called type I corneal healing, which implies the presence of fine and strictly linear opacities along the incisions. In cases of impaired healing (type II—III) the refractive effect diminishes over time, mainly due to an increase in corneal rigidity [4, 27]. The risk of traumatic corneal rupture is, however, higher in type I healing. Morphological examination of post-RK eyeballs enucleated following severe blunt trauma allowed I.P.Khoroshova—Maslova to conclude that, owing to inhibition of keratoblastic proliferation, healing of corneal incisions should be considered an *incomplete* rather than protracted process [28].

A hyperopic shift in the late post-RK period should be regarded as an enhancement of the refractive effect caused by further flattening of the central cornea. The mechanism of corneal curvature change suggests that it might be due to an increase in IOP and/or age-related decrease in corneal rigidity. The possibility of age-related changes of biomechanical properties of the fibrous tunic of the eyeball (cornea in particular) was proved in large clinical studies [29].

As revealed by comparing biomechanical parameters of the cornea in patients from different age groups (18—45 and 60—75 years of age), both corneal resistance factor (CRF) and corneal hysteresis (CH) decrease with age by 1.3 and 1.1 mmHg on the average, correspondingly, while the central cornea becomes thinner by the average of 22 μm. These changes indirectly indicate an age-related decrease in corneal rigidity. One should also take into account that the risk of glaucoma development might be higher in myopic patients [29—36].

Yet there are no published data on the mechanism of progressive hyperopia following RK.

The aim of the present study was to investigate possible causes of progressive shift toward hyperopia in the late period after radial keratotomy.

Material and methods

The study enrolled 33 subjects (64 eyes) who had undergone radial keratotomy earlier in their lives and were now referred for ophthalmic examination due to suspected glaucoma. Depending on whether or not the patients exhibited a progressive hyperopic shift, they were divided into two groups: group I (controls) of 15 patients (29 eyes with no late refractive changes following RK), and group II (main group) of 18 patients (35 eyes with signs of progressive hyperopia in the late post-RK period).

Ophthalmic examination, basic and special, was held 24—32 years after the surgery (26.8 years on average).

The number and type of keratotomy incisions was determined during biomicroscopy. Bidirectional applanation with Ocular Response Analyzer (ORA, Reichert, USA) enabled assessment of intraocular pressure and biomechanical properties of the cornea by providing CRF and CH values, and central corneal thickness (measured with an in-built pachymeter).

Non-applanational techniques were also employed for IOP measurement, that is dynamic contour tonometry (Pascal tonometer, Zeimer, Switzeland), point contact tonometry (ICare Pro rebound tonometer, Tiolat, Finland), and transpalpebral tonometry (digital portable Diaton tonometer, Russia). Besides tonometry, gonioscopy, and ophthalmoscopy, glaucoma diagnostics included 30-2 SITA-Standard automated perimetry (Humphrey Field Analyzer i750, Carl Zeiss Meditec, Germany) and confocal scanning laser ophthalmoscopy of the optic nerve head (ONH) and retina (HRT III, Heidelberg Engineering, Germany). The average loss of sensitivity (mean deviation, MD), pattern standard deviation (PSD) along with ONH stereometric parameters (most of all, linear cup/disk ratio) were evaluated.

The results were put on record and then analyzed with nonparametric statistical methods (due to small number of observations and abnormal distribution). For quantitative data sets the median and the first and third quartiles were calculated. The reliability of independent samples was assessed with Wilcoxon—Mann—Whitney U-test.

Results and discussion

Comparison of biomicroscopy appearances revealed no significant difference in number of keratotomy incisions between groups I and II (median values of 12 and 10 respectively). The mean spherical equivalent refraction was of 0 diopters in group I and of +3.5 diopters in group II.

Central corneal thickness differed reliably between the groups: its median value in group II was 56 microns less than that in group I ($p<0.05$). This fact indirectly indicates dissimilarities in initial biomechanical properties of the corneas under study, particularly, lower rigidity at baseline in group II as compared with group I.

It should be noted that interpretation of biomechanical indices of post-RK corneas calculated from the results of bidirectional applanation is complicated due to generally atypical waveforms from the central cornea. Therefore only the least distorted signals (referred to as ‘conditionally typical corneograms’) were selected for further analysis (**fig. 1**).

Conditionally typical corneograms (the first variant in fig. 1) were observed in about half of the patients and

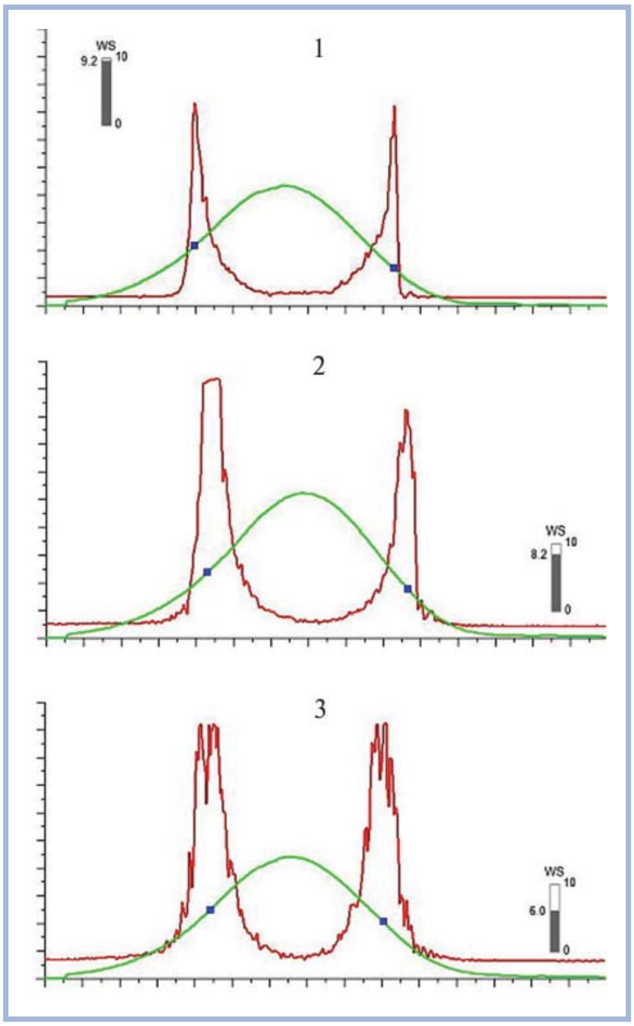

Fig. 1. **Corneograms following RK:**

1 — conditionally typical; 2 — with abnormality of the first peak; 3 — atypical.

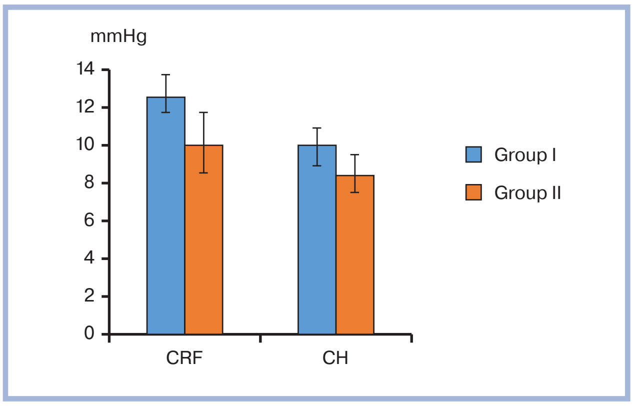

Fig. 2. **Distribution diagrams of biomechanical indices in the two study groups (error bars indicate interquartile ranges)**

associated with high reliability of IOP and biomechanical measurements. However, the figures *should not* be considered *alone, but* in conjunction with visual appearance of the curves, because reshaping of applanation surface of the cornea usually causes overstatement of both corneal compensated and Goldman-correlated IOP and, perhaps, inaccuracy in biomechanical measurements.

CRF and CH values were found to be 2.4 and 1.6 times less, respectively, in patients with hyperopic shift following RK as compared to the controls (**fig. 2**).

Discovered changes in biomechanical parameters together with a significantly thinner central cornea in the main group as compared to the controls suggest that the shift toward hyperopia in the post-RK period is due to reduced corneal resistance to deformation under load (reduced corneal rigidity, in other words). The latter is likely to be determined by individual and age-related peculiarities of corneoscleral biomechanics. Additionally, biomechanical responses of the fibrous tunic may be affected by scleral changes associated with myopia.

Since the Pascal dynamic contour tonometer demonstrated the highest repeatability of IOP measurements, its readings were specifically chosen for further analysis. Borderline IOPs with a tendency toward hypertension were found in both groups (interquartile range of IOP 17.8÷22.4 mmHg in the hyperopic shift group and 16.3÷20.6 mmHg in the controls; the maximum IOPs 31.6 mmHg and 27.7 mmHg respectively). Nevertheless, changes in retinal light sensitivity and optic nerve head parameters were more pronounced in the control group (**see the table**).

From these results, a conclusion may be drawn that progressive hyperopia in the late post-RK period develops under certain conditions — namely, reduced corneal rigidity, elevated IOP, and fine (not coarse) incision scarring. The reduction in corneal rigidity is likely to result from an interaction between three factors: initial, surgical (making of incisions), and age-specific. The natural question then arises as to why, despite a tendency

Static perimetry and confocal ophthalmoscopy results

Indices	Median		Quartile 1		Quartile 3	
	Group					
	1	2	1	2	1	2
MD, dB	–3.63	–1.72	–5.72	–2.70	–1.39	–0.84
PSD, dB	2.16	1.91	1.72	1.71	4.46	2.38
Cup/disk ratio	0.53	0.30	0.28	0.16	0.64	0.49

toward ocular hypertension in both groups, retinal and ONH changes in post-RK patients with progressive hyperopia are less pronounced than those in the controls. A possible explanation that we provide follows from our view of rigidity differences between different parts of the fibrous tunic [30]. Normally, the sclera possesses the highest resistance to plastic deformation, while the lamina cribrosa is the weak link, or, in other words, the parts can be arranged in the following descending order of rigidity: sclera — cornea — lamina cribrosa. This rule might be broken if a reduction in corneal rigidity occurs due to the above-mentioned reasons. Because of incomplete scarring of corneal incisions, not the lamina cribrosa but the cornea becomes the weakest part of the fibrous tunic. Under elevated IOP (and, perhaps, on account of age-related biomechanical changes) the cornea undergoes gradual deformation (mid-peripheral corneal steeping and central corneal flattening), which manifests as enhancement of the refractive effect — a hyperopic shift. At the same time, the lamina cribrosa in these patients appears less exposed to pressure. The latter apparently postpones the development and/or slows down the progression of glaucomatous optic neuropathy.

Conclusions

Two major contributors to the hyperopic shift in the late post-RK period can be suggested: elevated IOP and reduced corneal rigidity.

Selective involvement of post-RK patients, despite equally elevated IOP, may be due to dissimilar corneal rigidity at baseline.

Under these conditions, not the lamina cribrosa but the cornea becomes the target of biomechanical changes in glaucoma.

From the practical standpoint, all patients with progressive hyperopia in the late period after radial keratotomy should be considered at increased risk of glaucoma.

Author contributions:
Study conception and design — S.A., A.A., S.V.
Acquisition and handling of data — S.V.
Statistical analysis of data — S.V., A.A.
Drafting of manuscript — S.A., A.A., S.V.
Critical revision — S.A.

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