Acta Scientific Ophthalmology (ISSN: 2582-3191)
Volume 9 Issue 1 January 2026
Research Article

Use of An Automated Questionnaire to Assess Quality of Life in Patients with Keratoconus After Corneal Segments Implantation

EG Solodkova[1], SB Izmailova[2], SV Balalin[1]*, OV Yuferov[1], IN Zakharov[3] and VA Sivolobov[1]

[1]Eye Microsurgery Named After Academician S.N. Fedorov, Volgograd Branch, Volgograd, Russia

[2]Eye Microsurgery Named After Academician S.N. Fedorov, Moskau, Russia

[3]Volgograd State Technical University, Strength of Materials Department, Russia

***Corresponding Author:** SV Balalin, Eye Microsurgery Named After Academician S.N. Fedorov, Volgograd Branch, Volgograd, Russia.

Received: May 22, 2026
Published: June 25, 2026

Abstract

Implantation of intrastromal corneal ring segments (ICRS) is considered one of the key surgical rehabilitation methods for patients with progressive keratoconus.

Purpose: To perform a comparative analysis of clinical and functional outcomes and visual quality of life in patients with keratoconus after standard versus personalized ICRS implantation, using a custom electronic questionnaire based on the NEI VFQ 25.

Materials and Methods: The study included 204 patients (204 eyes) with progressive stage II–III keratoconus, randomized into two groups: personalized ICRS implantation based on a corneal "digital twin" (n = 92) and standard implantation according to the Keraring nomogram (n = 112). Uncorrected visual acuity (UCVA), best corrected visual acuity (BCVA), higher order aberrations (HOAs), and visual quality of life were assessed using a modified electronic NEI VFQ 25 questionnaire supplemented with questions about photic phenomena and neuroadaptation time. Follow up visits were carried out preoperatively and at 1, 6, 12, and 24 months.

Results: In both groups ICRS implantation led to significant improvement in UCVA and BCVA and to a reduction in HOAs; however, the improvement was more pronounced with the personalized approach ($p < 0.001$). The total score on the modified NEI VFQ 25 increased significantly in both groups, but the gain and the scores on subscales for visual functioning, social functioning, adaptation to glare and halos, and neuroadaptation time were substantially higher in the study group ($p < 0.001$). Strong positive correlations were found between functional measures and the composite quality of life score, and moderate inverse correlations between photic complaints and aberration parameters.

Conclusion: Personalized ICRS implantation based on a corneal "digital twin" provides not only superior functional outcomes but also greater improvement in visual quality of life and tolerance of photic phenomena compared with the standard technique, supporting the advisability of implementing biomechanically guided planning in clinical practice.

Keywords: Keratoconus; Mathematical Biomechanical Model of the Cornea; Automated Questionnaire; Quality of Life Assessment; Intrastromal Corneal Ring Segments

Keratoconus is a progressive, noninflammatory, bilateral corneal disorder characterized by thinning, weakening, and ectasia of its paraxial zones, leading to distortion of the corneal surface. Vision loss occurs primarily because of the development of irregular astigmatism and myopia, and secondarily as a result of secondary corneal scarring [1].

Intrastromal corneal ring segment (ICRS) implantation is a modern, high-technology surgical treatment for keratoconus and other corneal ectasias, widely used both worldwide and in Russia [2].

At the Volgograd branch of the Federal State Autonomous Institution "National Medical Research Center 'MNTK 'Eye Microsurgery' named after acad. S.N. Fedorov" of the Ministry of Health of Russia, a personalized approach to ICRS implantation has been developed by optimizing the choice of segment sizes and positions based on a personalized mathematical biomechanical model — the so-called corneal "digital twin" [3].

In medical practice, increasing attention is being paid to the concept of quality of life when studying treatment outcomes; this concept reflects the subjective sense of well-being in physical, psychological, and social domains [4,5].

For objective measurement of quality of life after ophthalmic interventions, standardized questionnaire methods are used; among them, the National Eye Institute Visual Function Questionnaire (NEI-VFQ-25), developed by the United States National Eye Institute, is widely employed [6–8]. It comprises three question blocks that assess daily living, communicative, and emotional problems related to the disease, as well as the subjective evaluation of visual function before and after treatment. This questionnaire is based on a 5-point scale for rating the severity of negative states and allows correlation of patients' subjective experiences with quantitative measures of vision.

At the Volgograd branch, a method for assessing visual quality of life has been proposed using an electronic questionnaire derived from the NEI-VFQ-25 and supplemented with six questions about patients' sensitivity to optical phenomena that may occur after corneal surgery. A Certificate of Registration for the software package, No. 2026610138, was issued on 13 January 2026.

Purpose

To perform a comparative analysis of clinical-functional outcomes and quality of visual life using the developed program in patients with keratoconus before and after standard and personalized intra-stromal corneal ring segment implantation techniques.

Materials and Methods

We evaluated treatment outcomes in 204 patients (204 eyes) who underwent surgery at our clinic for progressive keratoconus of stages II and III (Amsler–Krumeich classification).

Inclusion criteria were corneal thickness at the thinnest point less than 450.0 μm but not less than 380 μm, maximum keratometry value not exceeding 65.0 D, absence of corneal opacities, no prior corneal surgery, and no acute inflammatory disease of the anterior segment. Patients showed an increase in keratometry readings of ≥1.0 D, a decrease in pachymetric measurements of 7.0 ± 2.0 μm over the course of one year, and a need to change spectacle or contact lens correction during the preceding two years.

Patients were randomized into groups:

- Group 1, primary — patients operated on using a modified personalized technique for intracorneal ring segment (ICRS) implantation based on a corneal "digital twin" — 92 patients, 92 eyes;
- Group 2, control — patients operated on using the standard ICRS implantation technique, with selection of segment number, characteristics, and position in the cornea according to the Keraring nomogram — 112 patients, 112 eyes.

The demographic characteristics of the study groups and the keratoconus stages observed in the groups are presented in Table 1. Bilateral disease was observed in all examined patients (100%). Thus, the observed groups were homogeneous with respect to age, sex distribution, and the stages of disease detected. Follow-up visits were conducted at 1, 6, 12, and 24 months.

For each patient in the primary group, a personalized geometrical and biomechanical finite-element model of the cornea was constructed and analyzed using data obtained from the Pentacam AXL and Corvis ST (OCULUS Optikgeräte GmbH, Germany) and the Comsol Multiphysics modeling system. The model described changes in corneal topography, biomechanical properties, and stress–strain state under external loads during diagnostic and surgical procedures, including virtual loading of the cornea with implants having various parameters [10,11]. Based on the computational stage of the work, the optimal intrastromal segment option and the best tunnel position were selected in each case.

Before and at the follow-up visits (postoperative day 1, and months 1, 6, 12, and 24), all patients enrolled in this study underwent visual acuity testing using a Reichert AP 250 projector (Reichert Inc., USA) with measurement of uncorrected and best-corrected visual acuity (UCVA and BCVA). Subjective refraction was determined by manifest refraction with corrective lenses on the Reichert device (Reichert Inc., USA). Mean preoperative and postoperative UCVA and BCVA values were calculated according to J. Holladay's rule: acuities were converted to LogMAR units and averaged, then the resulting mean LogMAR value was converted back to decimal acuity using the following scale: 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.8; 1.0; 1.3 [12].

Number of patients (eyes)	Modified n = 92	Standard method n = 112	p-value*
Age (years) M ± σ Median Min; max	32,19 ± 8,34 32,5 (18,0; 47,0)	30,05 ± 7,65 28,0 (18,0; 47,0)	*0,357
Women	22 (23,91%)	30 (26,78%)	
Men	70 (76,09%)	82 (73,21%)	
Keratoconus stage	2,64 ± 0,61	2,84 ± 0,61	*0,196

Table 1: Demographic characteristics and disease stage in the observation groups.

Note: *U – Mann–Whitney test.

Corneal higher-order aberrations (HOAs) were assessed using the Pentacam HR system and computed from Zernike polynomials up to 6th order for a 6-mm pupil zone. The study analyzed RMS HOAs, Coma0, Coma90 (Z3 ± 1), and spherical aberration (SphAb, Z4,0); these values were extracted from the aberrometry module, which takes into account both the anterior and posterior corneal surfaces [13,14].

To assess quality of life related to visual function, questionnaires were administered preoperatively and at follow-up visits 1, 6, 12, and 24 months after surgical treatment. The questionnaire comprises 25 items that form 12 subscales: General Vision (GV), Ocular Pain (OP), Near Activities (NA), Distance Activities (DA), Vision-specific Social Functioning (SF), Vision-specific Mental Health (MH), Role Difficulties (RD), Dependency (Dp), Driving (Dr), Color Vision (CV), and Peripheral Vision (PV) [15]. All questionnaire items were grouped by subscale; responses on the NEI VFQ-25 were recoded so that higher scores represented better functioning. Each response was then transformed to a 0–100 scale and expressed as a percentage. Thus, higher calculated scores indicated better visual functioning and, consequently, higher quality of life [15].

The program is based on the use of the cloud web service Google Forms within a personal Google account or Google Workspace, offering extensive functionality.

The program consists of two parts: the questionnaire module, the module for analysis of the collected results.

After patients complete the questionnaires, a CSV file with the results can be downloaded from the site.

Statistical analysis of the obtained results was performed using SPSS Statistics for Windows (version 22.0, IBM Corp.). To compare group homogeneity, the Mann–Whitney U test was used; data are presented as mean (M), standard deviation (σ), median (Me), quartiles (Q1; Q3), as well as minimum and maximum values. To determine differences between results at various follow-up time points relative to baseline within each group, the Wilcoxon signed-rank test was applied. When the critical value exceeded the empirical value and the significance level was p < 0.05, the difference was considered statistically significant.

Results

Comparison of UCVA and BCVA, as well as preoperative ABP values between groups using the Mann–Whitney test showed no significant differences and confirmed their clinical homogeneity (p < 0.05).

As a result of corneal segment implantation, both UCVA and BCVA improved significantly in patients in both groups (p < 0.001). The visual acuity dynamics (logMAR) in the groups at the follow-up time points are shown in Figures 1a, 1b and 2a, 2b.

Comparison of visometry results between groups at the follow-up time points showed a significantly greater increase in both UCVA and BCVA in the main group at all observation times compared with the standard group (p < 0.001).

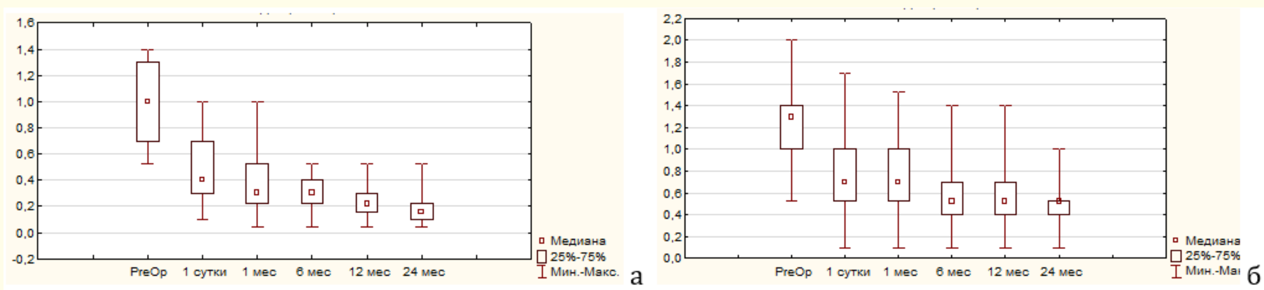

Figure 1: Dynamics of uncorrected distance visual acuity (logMAR) in the treatment group (a) and the control group (b) at follow-up time points

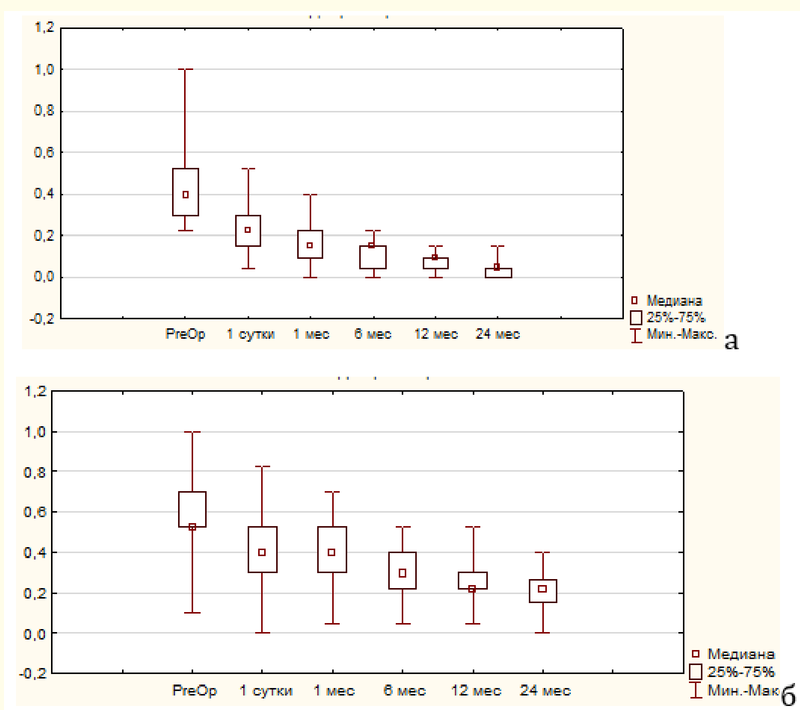

Figure 2: Dynamics of corrected distance visual acuity (logMAR) in the treatment group (a) and the control group (b) at follow-up time points.

The improvement in visual acuity in the groups was also associated with a significant reduction in the median RMS of higher-order aberrations (RMS HOA): in the main group from the first day after surgery, and in the control group from the 1-month follow-up (Figure 3a, b) ($p < 0.001$). Between-group comparison demonstrated a significantly greater decrease in RMS HOA in the main group at all observation times ($p < 0.001$).

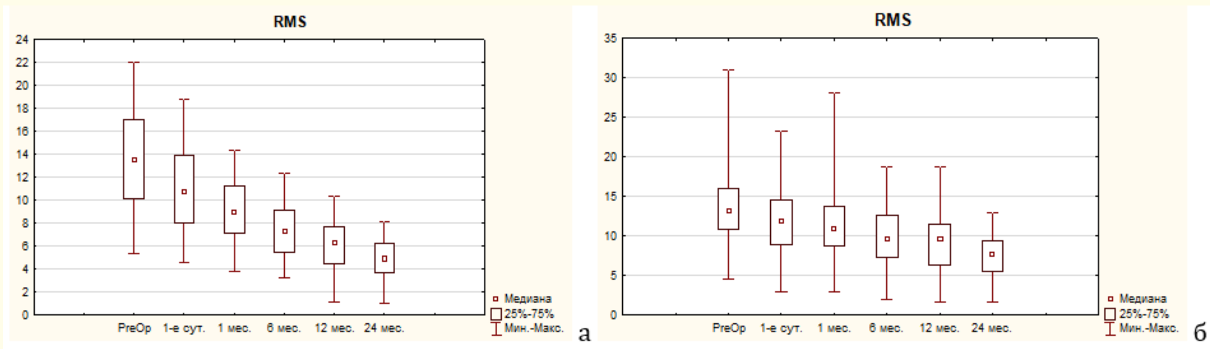

Figure 3: Dynamics of RMS higher-order aberrations in the treatment group (a) and the control group (b) at follow-up time points.

When analyzing changes in the levels of individual higher-order aberrations in both groups, a significant normalization of AVP (Z3-1) Coma 90 was observed at all follow-up time points, beginning from the first day (Figure 4 a, b). The difference between the groups reached statistical significance only at the late follow-up — 24 months ($p = 0.02$).

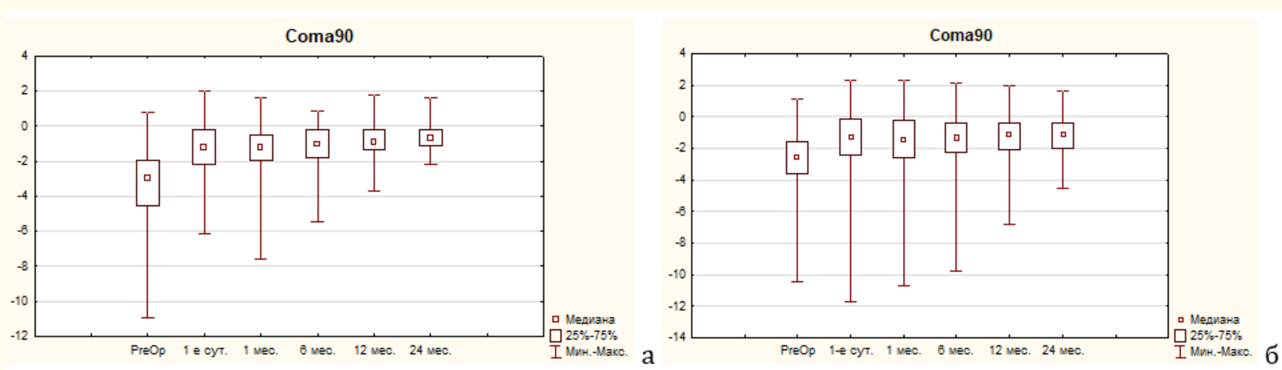

Figure 4: Dynamics of coma (Coma 90, Z3–1) in the treatment group (a) and the control group (b) at follow-up time points.

Changes in HOA Coma 0 (Z3+1) were not statistically significant in either group at any follow-up time point ($p > 0.05$). Implantation of the ICRS led to a significant normalization of HOA Spherical aberration (Z40) in both groups as early as the first postoperative day, and this trend persisted at all follow-up time points ($p < 0.001$) (Figure 5 a, b). Median SphAb values decreased more markedly in the primary group, and the differences between groups were statistically significant at all follow-up time points ($p < 0.05$).

Increase in UCVA and BCVA, as well as a decrease in RMS AVP values, indirectly contributed to improvements in patients' quality-of-life measures.

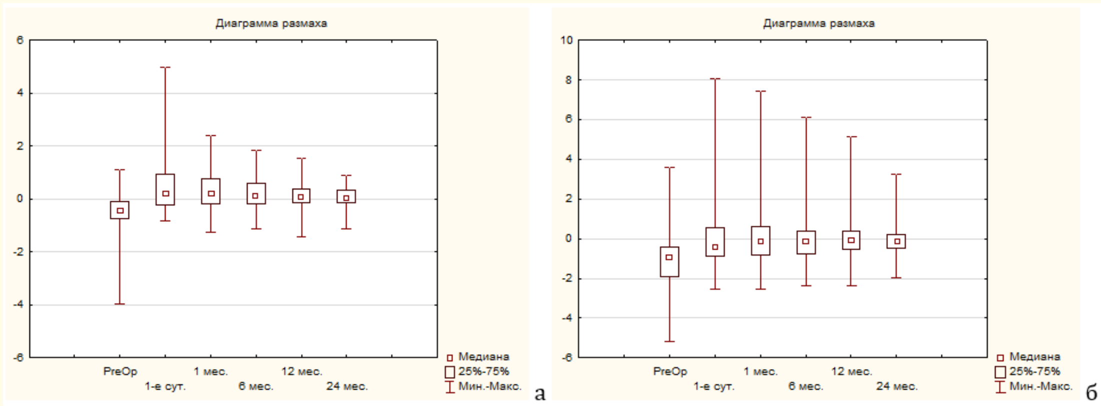

Figure 5: Dynamics of spherical aberration (Z40) in the treatment group (a) and the control group (b) at follow-up time points.

As shown in Table 2, the overall quality-of-life score increased significantly in both groups at all follow-up points ($p < 0.001$). However, the dynamics differed: in the primary group the score rose from 55.82 points preoperatively to 69.70 points at 24 months (+13.88 points, +24.9%), whereas in the control group it rose from 56.44 preoperatively to 64.10 at the maximal follow-up (+7.66 points, +13.6% at 24 months). Intergroup differences were statistically significant at 6, 12, and 24 months ($p < 0.05$), indicating greater effectiveness of the personalized IOL implantation technique. The largest contributions to the increase in the overall quality-of-life score in the primary group were improvements in social functioning (+27.27 points, +37.6%), distance visual function (+35.69 points, +78.9%), near visual function (+29.78 points, +53.2%), a 69.1% reduction in the mental health score (decrease in anxiety), and a 72.1% reduction in dependence on outside help.

During analysis of the survey results on adaptation to glare and halos, it was noted that in the study group the mean score increased by 59.6% (from 49.11 points preoperatively to 78.37 points at 24 months of follow-up), while in the control group it increased by 38.3% (from 50.78 points preoperatively to 70.22 points at 24 months). Differences between the mean scores were statistically significant at all follow-up time points ($p < 0.01$).

Assessment of the time required to adapt to the new optical conditions in the study group showed a gradual increase of 14.99% (from 60.57 points preoperatively to 75.56 points at 24 months of follow-up), whereas in the control group a sharp decrease of 37.7% in this score was observed at the 1-month follow-up (from 53.13 points preoperatively to 33.13 points), indicating a longer period of neuroadaptation with the standard method.

Subscales	**PreOp**		**1 *мес.***		**6 мес.**		**12 мес.**		**24 мес.**	
	1 гр.	**2 гр.**	**1 гр.**	**2 гр.**	**1 гр.**	**2 гр.**	**1 гр.**	**2 гр.**	**1 гр.**	**2 гр.**
General health status	53,57* ± 3,54	55,38* ± 3,46	67,86** ± 3,87	61,24* ± 3,75	72,40** ± 2,90	66,91** ± 2,87	78,60** ± 2,54	70,20** ± 3,02	80,33** ± 3,19	73,40** ± 3,10
Overall health rating	51,43* ± 3,31	55,00* ± 3,39	71,43** ± 3,22	67,42** ± 3,14	75,25** ± 2,84	70,41** ± 3,03	77,48** ± 3,62	71,29** ± 3,47	81,50** ± 3,51	73,35** ± 3,25
Eye pain	50,93* ± 2,54	49,44* ± 2,46	62,14* ± 2,77	56,13* ± 2,89	68,41** ± 2,97	61,42** ± 3,07	75,23** ± 3,10	65,44** ± 3,24	78,25** ± 3,20	69,98** ± 3,37
Near visual functions	55,95* ± 3,78	57,71* ± 3,85	74,52** ± 3,22	67,12** ± 3,36	75,58** ± 3,28	69,87** ± 3,41	77,90** ± 3,36	70,53** ± 3,50	85,73** ± 3,46	75,15** ± 3,88
Distance visual functions	45,24* ± 3,85	46,25* ± 3,94	69,05** ± 3,52	60,13* ± 3,56	73,96** ± 3,77	64,68** 3,57 ±	75,5** ± 3,33	68,36** ± 3,44	80,93** ± 3,63	70,29** ± 3,81

Social functioning	72,50* ± 5,51	69,96* ± 4,01	85,71** ± 4,51	80,19** ± 4,33	89,84** ± 4,25	83,75** ± 4,31	95,42** ± 3,96	85,15** ± 3,92	99,77** ± 4,06	88,20** ± 4,10
Mental health	56,82* ± 3,32	55,94* ± 3,41	31,64** ± 2,50	44,46** ± 2,85	25,46** ± 2,87	39,16** ± 3,19	22,25** ± 2,63	35,17** ± 2,78	17,54** ± 1,97	29,44** ± 2,10
Role difficulties	48,21* ± 3,99	50,31* ± 4,05	25,63** ± 2,98	32,19** ± 3,10	21,49** ± 2,78	29,40** ± 3,09	19,80** ± 2,72	25,20** ± 2,89	15,76** ± 1,89	20,12** ± 2,05
Dependence on others	58,81* ± 4,15	55,63* ± 4,43	26,86** ± 3,32	27,71** ± 3,40	22,19** ± 3,25	25,26** ± 3,14	20,14** ± 2,54	23,18** ± 2,36	16,43** ± 2,05	19,41** ± 1,99
Driving	59,10* ± 4,53	61,43* ± 4,34	68,41** ± 4,10	64,67* ± 4,24	72,34** 3,99 ±	67,36** ± 3,87	75,98** ± 3,36	71,14** ± 3,59	79,60** ± 3,70	72,21** ± 3,47
Color vision	71,43* ± 4,31	73,55* ± 4,52	96,86** ± 3,98	92,88** ± 4,15	98,63** ± 4,10	95,14** ± 3,79	98,46** ± 3,75	97,10** ± 4,04	99,50** ± 3,95	98,45** ± 3,89
Peripheral vision	53,57* ± 3,49	55,69* ± 3,38	71,43** ± 2,99	65,63* ± 3,05	75,48** ± 3,28	68,88** ± 3,45	80,50** ± 3,42	72,65** ± 3,31	86,44** ± 3,51	78,94** ± 3,76
Glare and halo adaptation	49,11* ± 2,49	50,78* ± 2,71	69,64** ± 3,21	59,14*** ± 2,95	73,90 ± 3,14	63,65* ± 3,62	76,41** ± 3,94	65,14** 3,50 ±	78,37** ± 3,46	70,22** ± 3,67
Adaptation time	54,86* ± 3,12	53,13* ± 3,35	60,57* ± 2,84	33,13** ± 2,56	65,96** ± 3,05	38,90** ± 2,95	69,18** ± 3,10	45,42* ± 3,26	75,56** ± 3,44	58,28* ± 3,50
Total score	55,82* ± 3,70	56,44* ± 3,66	63,41* ± 3,35	58,00* ± 3,38	65,06** ± 3,31	60,3* ± 3,38	67,35** ± 3,24	61,86* ± 3,31	69,70** ± 3,22	64,10** ± 3,28

Table 2: Subscale scores of the electronic questionnaire in the groups at follow-up time points.

The Spearman correlation analysis showed a strong positive correlation ($r = 0.65–0.82$, $p < 0.001$) between the total score and the UCVA, the point-based assessment of distance visual functions and the BCVA, and between social functioning and the UCVA. A moderate negative correlation ($r = −0.45–0.58$, $p < 0.01$) was observed between the assessment of adaptation to glare/haloes and APV Coma, and between adaptation time and corneal APV RMS. These data confirm that subjective assessments of quality of life are closely related to objective functional outcomes, but are not a direct reflection of them.

Conclusion

A personalized technique for ICRS implantation provides comprehensive rehabilitation for patients with keratoconus, including not only restoration of visual function but also normalization of psychoemotional status, recovery of working capacity, and social activity, which together lead to a significant improvement in patients' quality of life and their successful reintegration into society.

An automated optimized questionnaire was developed to assess vision-related quality of life in keratoconus patients after ICRS implantation; it enables more complete information on the patient's subjective perception of life. The significantly greater increase in questionnaire scores with the personalized approach compared with the standard ICRS implantation technique ($p < 0.01$) confirms better subjective perception of quality of life by patients.

Conflict of Interest

There is no conflict of interest.

Funding

This study was supported by a grant from the Russian Science Foundation (№25-25-00303, https://rscf.ru/project/25-25-00303).

Bibliography

1. Sinha R., *et al*. "Management of keratoconus: A review". *Indian Journal of Ophthalmology* 58.3 (2010): 263-268.

2. Izmailova SB. "Medical and technological system of surgical treatment of progressive keratectasia of various origins: Abstract of a Doctor of Medicine dissertation". (2014): 50.

3. Solodkova EG., *et al*. “Streamlined approach to corneal ring implantation based on mathematical modelling”. *Russian Journal of Clinical Ophthalmology* 25 (2025): 7-18.

4. Sevostyanov EN and Gorskova EN. “Keratoconus plus”. Chelyabinsk: “PIRS”, (2006): 148.

5. Novik AA and Ionova TI. “Guide to the study of quality of life in medicine”. (2002): 314.

6. Belghmaidi S., *et al*. “Measurement of visual function among patients undergoing corneal transplantation using the VF-14 index in Morocco”. *Journal Français D’ophtalmologie* 39.10 (2016): 866-871.

7. Drzyzga K., *et al*. “Quality of Life and Mental State After Sight Restoration by Corneal Transplantation”. *Psychosomatics* 57.4 (2016): 414422.

8. Saunier V., *et al*. “Vision-related quality of life and dependency in French keratoconus patients: Impact study”. *Journal of Cataract and Refractive Surgery* 43.12 (2017): 1582-1590.

9. Terentyeva AE. “Optimized technology for the correction of high myopia based on femtosecond laser intrastromal implantation of a ring-shaped polymer implant: Abstract of a PhD thesis”. Moscow (2023): 26.

10. Pinsky PM., *et al*. “Numerical-Simulation of topographical alterations in the cornea after ICR (intrastromal corneal ring) placement”. *Investigative Ophthalmology and Visual Science* 36.4 (1995): 309.

11. Kling S., *et al*. “Finite-Element Modeling of Intrastromal Ring Segment Implantation into a Hyperelastic Cornea”. *Investigative Ophthalmology and Visual Science* 54.1 (2013): 881-889.

12. Rosser DA., *et al*. “How sensitive to clinical change are ETDRS logMAR visual acuity measurements?” *Investigative Ophthalmology and Visual Science* 44 (2003): 3278-3281.

13. Colak HN., *et al*. “Comparison of corneal topographic measurements and high order aberrations in keratoconus and normal eyes”. *Contact Lens and Anterior Eye* 39 (2016): 380-384.

14. Delgado S., *et al*. “Correlation of higher order aberrations in the anterior corneal surface and degree of keratoconus measured with a Scheimpflug camera”. *Archivos de la Sociedad Española de Oftalmologia* 91 (2016): 316-319.

15. Trubilin VN., *et al*. “Methods of studying “quality of life” in ophthalmological practice: Tutorial”. (2016): 28.