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ORIGINAL RESEARCH

Study on Visual Quality After Cataract Surgery and Goniosynechialysis in Patients with Primary Angle-Closure Glaucoma and Cataracts

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Objective: To assess the visual quality in patients with primary angle-closure glaucoma (PACG) complicated by cataracts after cataract phacoemulsification with intraocular lens (IOL) implantation and goniosynechialysis, and to explore the relationship between pupil size and visual quality.

Methods: A retrospective, non-randomized study was conducted, including 65 PACG patients (75 eyes) who underwent cataract surgery with IOL implantation and goniosynechialysis from July 2021 to June 2023, as well as a control group of cataract-only patients. Visual quality was evaluated using objective and subjective methods at least 3 months postoperatively. PACG patients were divided into large-pupil (≥5 mm) and normal-pupil (<5 mm) groups. Visual quality parameters were compared among groups, and correlations between pupil size and objective visual quality measures were analyzed.

Results: Visual Parameters: The large-pupil PACG group showed significantly higher higher-order aberrations, including coma and spherical aberrations, compared to both the cataract and normal-pupil groups. Contrast sensitivity was also worse in the large-pupil group. Visual Quality Questionnaire: The large-pupil group reported higher scores for night glare and difficulty driving at night. Correlations: Pupil size was positively correlated with higher-order aberrations and negatively correlated with contrast sensitivity.

Conclusion: Pupil dilation is a major factor affecting postoperative visual quality in PACG patients, even after surgery. Larger pupil size significantly increases higher-order aberrations and reduces contrast sensitivity. Techniques like pupil suturing may help improve visual quality in these patients.

Keywords: primary angle closure glaucoma, visual quality, contrast sensitivity, higher-order aberrations

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Introduction

Glaucoma is one of the leading causes of irreversible blindness worldwide.[1,2] There are various types of glaucoma, all of which ultimately cause progressive and irreversible damage to the optic nerve, leading to visual field defects and, eventually, blindness.[3] Primary glaucoma can be classified into three main types: open-angle, angle-closure, and congenital. Primary angle-closure glaucoma (PACG) is a type of glaucoma caused by primary angle closure, leading to acute or chronic elevation of intraocular pressure, which may be accompanied by glaucomatous optic disc changes and visual field damage. The most common cause of angle closure is relative pupillary block: a small space between the lens and the iris increases resistance to the flow of aqueous humor through the pupil, creating a pressure difference that causes the iris to bow forward and block the angle.[4] Over time, the iris may adhere to the angle, and prolonged adhesion eventually results in angle closure, preventing aqueous humor outflow. Additionally, as age increases, the volume of the lens enlarges, further increasing the risk of pupillary block. For PACG patients who do not respond well to intraocular pressure-lowering medications and have coexisting cataracts, the recommended first-line treatment is cataract extraction

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combined with intraocular lens implantation, accompanied by angle separation under gonioscopy.[5,6] The advantage of this combined surgery lies in the fact that the natural lens of the human eye is thicker than 4 millimeters, while an intraocular lens is less than 1 millimeter thick. Therefore, the intraocular lens creates more space between it and the iris, relieving the pupillary block while the angle separation performed during the surgery opens the pathway for aqueous humor outflow. The emergence of this combined surgery has gradually evolved from simple glaucoma surgery into a refractive surgery and has now become an important surgical option for PACG patients. Moreover, as living standards continue to improve, glaucoma patients' expectations after surgery have also risen, shifting from merely reducing intraocular pressure and restoring vision to pursuing better visual quality.

The evaluation of visual quality has long been a research topic in the fields of ophthalmology and optometry. The evaluation methods can be divided into two main categories: 1. Objective methods, including wavefront aberrations, modulation transfer function (MTF), and Strehl ratio (S/R). These methods primarily evaluate the imaging quality of the eye's optical system by measuring parameters such as aberrations and optical transfer function generated during the passage of light through the eye to assess the performance of the visual system; 2. Subjective methods, including visual acuity, contrast sensitivity function (CSF), and contrast visual acuity. These methods can not only evaluate the imaging quality of the eye's optical system but also assess the human eye's form vision function, that is, the ability of the human eye to perceive visual stimuli at different contrasts and spatial frequencies.

The evaluation of visual quality is closely related to the size of the pupil. Studies have shown that under normal circumstances, due to the relatively flat lens, the refractive index of the lens nucleus is higher than that of the cortex. When the pupil functions as an appropriate aperture, the eye's higher-order aberrations are at a lower level. However, as the pupil dilates, the different refractive indices encountered by light passing through the pupil region cause higher-order aberrations in the eye to increase exponentially.[7,8] In patients with acute angle-closure glaucoma, the damage to the sphincter pupillae often results in a pupil diameter greater than 5mm. Postoperatively, the edge of the artificial lens's optical section may be exposed within the pupil area, leading to abnormal visual quality assessments. Therefore, even if intraocular pressure is controlled and central vision improves postoperatively, the overall visual quality may not necessarily show significant improvement. An international study[9] reported that in cataract patients without other comorbidities, the effect of implanted intraocular lens (IOL) on higher-order aberrations was evaluated by examining the impact of pupil size, IOL decentration, and tilt angle. The study found that pupil size had the most significant influence on the observed higher-order aberrations, accounting for 54.9%. However, for patients with glaucoma combined with cataracts, most studies[10,11] have focused on postoperative intraocular pressure control and vision improvement, with only a few studies addressing the evaluation of postoperative visual quality in glaucoma patients.

This study selected patients with primary angle-closure glaucoma combined with cataracts and treated them with goniosynechialysis combined with phacoemulsification and intraocular lens implantation. The focus of the research is to evaluate the patients' postoperative visual quality, particularly to explore the relationship between different postoperative pupil sizes and various visual quality assessments, as well as the connection between subjective and objective visual quality evaluations. Through this study, we aim to provide clinical guidance on selecting the appropriate range of pupil sizes for patients with acute pupil dilation associated with angle-closure glaucoma combined with cataracts.

Subjects and Methods

Study Subjects

A retrospective analysis was conducted, selecting 45 patients with primary angle-closure glaucoma combined with cataracts who underwent cataract phacoemulsification with intraocular lens implantation and goniosynechialysis at our hospital's ophthalmology department from July 2021 to June 2023. Additionally, 20 patients with uncomplicated cataracts who underwent cataract phacoemulsification and intraocular lens implantation were included as a control group. This study has been approved by the Ethics Committee of the Affiliated Hospital of North Sichuan Medical College (File Number: 2024ER75-1). This study complies with the Declaration of Helsinki.

Inclusion Criteria

Patients with Angle-Closure Glaucoma: Patients with primary angle-closure glaucoma (PACG): Diagnosed with acute or intermittent PACG combined with cataracts[5], with goniosynechialysis closure of the angle > 180°, and IOP not controlled by medication. These patients underwent cataract phacoemulsification, intraocular lens implantation, and goniosynechialysis at our hospital; no other anti-glaucoma surgeries were performed. The best corrected visual acuity postoperatively was ≥4.8, and patients with low vision affecting visual function were excluded. Good compliance was ensured, and IOP remained <21 mmHg postoperatively and during follow-up, regardless of whether anti-glaucoma medication was used. No other surgical treatments were applied before or after the surgery. The same model of aspherical intraocular lens (Punome A1-UV, produced by Abo Nord Company, Beijing) was used in all surgeries. The patients were diagnosed with acute or intermittent PACG, with OCT showing the following retinal nerve fiber layer (RNFL) thickness: 70–90 µm in the nasal and temporal quadrants, 110–130 µm in the superior quadrant, and 120–140 µm in the inferior quadrant. Visual field examination showed an MD value ≤ −6. Patients were aged 50–65 years.

Cataracts without other comorbidities: Postoperative BCVA was ≥4.8, excluding cases where low vision affected visual function. The patients demonstrated good compliance, and the same model of aspheric intraocular lens (Promin A1-UV, produced by Beijing Aibo Technology Co., Ltd.) was used during surgery. Patients were aged 50–65 years, had undergone phacoemulsification cataract extraction combined with intraocular lens implantation, and had a pupil diameter < 5mm.

Exclusion Criteria

The exclusion criteria for study subjects were as follows: (1) amblyopia; (2) a history of fundus disease, intraocular disease, corneal disease, or ocular trauma that severely affected postoperative visual recovery; (3) postoperative complications such as hemorrhage, infection, intraocular lens dislocation, posterior capsule opacification, or macular edema; (4) severe systemic diseases such as diabetes or hypertension; (5) diseases affecting the clarity of the refractive media, such as pterygium, corneal leukoma, or corneal disease.

Study Methods

Study Grouping

All patients voluntarily signed informed consent forms and were divided into three groups: (1) Patients diagnosed with angle-closure glaucoma were divided into a PACG normal pupil group (pupil diameter < 5mm) consisting of 23 patients (25 eyes) and a PACG large pupil group (pupil diameter ≥ 5mm) consisting of 22 patients (25 eyes), according to the pupil diameter measured at least three months postoperatively; (2) The control group consisted of 20 patients (25 eyes) with cataracts without other comorbidities.

Surgical Methods

Before surgery, surface anesthesia was administered using proparacaine hydrochloride eye drops. A disposable ophthalmic scalpel was used to create a main incision at the 11 o'clock position. A 2.75mm clear corneal auxiliary incision was made at the 2 o'clock position using a 15-degree puncture knife, and a viscoelastic agent was injected. Continuous curvilinear capsulorhexis was performed, with the capsulotomy diameter being approximately 5mm. Hydrodissection was conducted, followed by phacoemulsification to remove the lens. For combined goniosynechialysis, a gonioscope was used during surgery to separate the synechial angle through the main incision using a lens repositioning hook. Finally, all patients received implantation of the Promin A1-UV aspheric intraocular lens, and the incision was sealed watertight. All surgeries were performed by the same experienced ophthalmologist.

Major Instruments and Equipment

CSV-1000 Contrast Sensitivity Test Light Box

The CSV-1000 is a commonly used tool for measuring contrast sensitivity,[12] employing sinusoidal gratings with high reliability. It measures contrast sensitivity across various spatial frequencies, specifically 3, 6, 12, and 18 cycles per degree (c/d) horizontally. Each spatial frequency group consists of 17 squares, each with a diameter of 3.8 cm. The first square, featuring the highest contrast vertical sinusoidal grating, is used for demonstration purposes, while the remaining eight pairs of squares, numbered 1 to 8, are used for testing. The contrast decreases by 0.17 log units from the 1st to the 3rd column of squares, and by 0.15 log units from the 3rd to the 8th column.

KR-1W TOPCON Wavefront Aberrometer

The KR-1W Wavefront Analyzer utilizes the Hartmann-Shack principle[13] and is equipped with three measurement systems using infrared laser light sources, enabling simultaneous coaxial measurements. It features automatic tracking and can simultaneously measure total eye aberrations, corneal aberrations, and pupil diameter. The measurement time for the two wavefront aberration parameters is 100ms, with a total of 2209 measurement points. The device allows up to 10 consecutive measurements and demonstrates excellent repeatability.

National Eye Institute Refractive Error Quality of Life Instrument (NEI-RQL)

The NEI-RQL is a questionnaire used to assess vision-related quality of life,[14] consisting of 42 items across 13 subscales. In this study, the NEI-RQL was translated into Chinese by a team of professional ophthalmologists and English teachers. A selection of items was chosen to survey patients' subjective symptoms, including dryness, vision fluctuations, night glare, halos, difficulty driving at night, fine motor tasks, long-duration reading, and overall visual satisfaction, totaling 8 indicators. The first 7 indicators were rated on a scale of 1 to 5, representing: no symptoms, very few symptoms, sometimes, frequently, and persistent. The final item on overall satisfaction was rated on a scale of 1 to 5, representing: extremely dissatisfied, somewhat dissatisfied, neutral, somewhat satisfied, and very satisfied.

Research Parameters

All patients underwent routine examinations, including slit-lamp examination, uncorrected visual acuity and corrected visual acuity (Standard Logarithmic Visual Acuity Chart, 5-point visual acuity record), intraocular pressure, visual field, and fundus examination, at least 3 months postoperatively. Patients were selected based on inclusion and exclusion criteria. Eligible patients were then tested in a dark environment using the CSV-1000 contrast sensitivity test box and the KR-1W wavefront aberrometer. Measurements included contrast sensitivity at various spatial frequencies, pupil diameter, S/R ratio, and high-order aberrations of the whole eye, with results recorded. Finally, the NEI-RQL Chinese questionnaire was completed. All examinations were conducted by the same ophthalmologist who had received professional training.

The main research parameters include: refractive status and best-corrected visual acuity, contrast sensitivity, whole-eye wavefront aberrations, and subjective visual perception.

Best-Corrected Visual Acuity

First, objective refraction is measured using an automated computer refractometer, followed by subjective refraction to record the best-corrected visual acuity and refractive status.

Contrast Sensitivity

Patients, wearing their best-corrected glasses, are seated 3 meters from the test box for measurement of each eye separately. After a dark adaptation period of at least 10 minutes, contrast sensitivity is tested. Patients are instructed to first observe the grating bars in the sample square and then find the matching grating bars among the following 8 pairs, indicating whether the bars are in the top or bottom square. Patients are encouraged to continue until no grating bars can be discerned. Results for spatial frequencies of 3, 6, 12, and 18 cycles per degree (c/d) are recorded, with all procedures performed by the same experienced physician.

Wavefront Aberration

Wavefront aberrations, pupil diameter, and Strehl ratio are measured using the KR-1W wavefront aberrometer in a dark room. The instrument uses an infrared laser source, and each eye is measured three times with the average value recorded. All procedures are performed by the same experienced physician.

Subjective Visual Perception

Under the guidance of the same experienced physician, patients complete the NEI-RQL Chinese questionnaire. The physician explains the meaning of each indicator to the patients and assists them in filling out the questionnaire and calculating the final scores.

Statistical Methods

Data are organized and analyzed using SPSS 26.0 statistical software. For normally distributed continuous data, comparisons between multiple groups are made using one-way ANOVA, with post hoc pairwise comparisons conducted using the Bonferroni test. Categorical data are expressed as frequencies (percentages) and compared between groups using chi-square tests. Pearson correlation analysis is used to assess correlations between continuous variables.$P<0.05$ is considered statistically significant.

Results

Basic Information of the Three Patient Groups

Chi-square tests and one-way ANOVA revealed no statistically significant differences in gender and age among the three patient groups ($P > 0.05$). See Table 1.

Comparison of Visual-Related Indicators Among the Three Patient Groups

One-way ANOVA showed no statistically significant difference in corrected visual acuity among the three patient groups ($P > 0.05$). The PACG large pupil group had higher pupil size, total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration compared to the cataract group and the PACG normal pupil group ($P < 0.05$). The S/R ratio was higher in the cataract group compared to the PACG normal pupil group and the large pupil group ($P < 0.05$). For contrast sensitivity A and B, the PACG large pupil group had lower scores than both the cataract group and the PACG normal pupil group ($P < 0.05$). For contrast sensitivity C and D, the PACG large pupil group < PACG normal pupil group < cataract group ($P < 0.05$). See Table 2.

Pearson Correlation Analysis of Overall Pupil Size with S/R Ratio, Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson correlation analysis found no significant correlation between pupil size and S/R ratio ($P > 0.05$). However, pupil size was positively correlated with total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration ($r = 0.229$ to 0.376, $P = 0.048$ to 0.001). See Table 3.

Table 1 Comparison of Basic Information Among the Three Patient Group

Indicator	Cataract (n=20)	PACG Normal Pupil (n=23)	PACG large Pupil (n=22)	χ2/F	P
Gender, n (%)				1.872	0.392
Male	12 (60.0)	9 (39.1)	11 (50.0)		
Female	8 (40.0)	14 (60.9)	11 (50.0)		
Age	56.90±4.54	57.48±4.74	57.32±7.05	0.060	0.942

Table 2 Comparison of Visual-Related Indicators Among the Three Patient Groups

Indicator	Cataract (n=25)	PACG Normal Pupil (n=25)	PACG Large Pupil (n=25)	F	P
Corrected visual acuity	4.88±0.08	4.86±0.08	4.87±0.08	0.190	0.827
Pupil size (mm)	4.43±0.59	4.29±0.37	5.80±0.60ab	60.824	<0.001
S/R	0.32±0.12	0.19±0.08a	0.17±0.06a	21.588	<0.001
Total aberration (um)	0.36±0.14	0.41±0.34	0.70±0.18ab	15.324	<0.001
Third-order aberration (um)	0.34±0.14	0.33±0.27	0.48±0.13ab	4.812	0.011
Fourth-order aberration (um)	0.19±0.10	0.22±0.21	0.41±0.17ab	12.760	<0.001
Coma (um)	0.33±0.13	0.36±0.27	0.51±0.13ab	6.650	0.002
Spherical (um)	0.21±0.11	0.23±0.22	0.47±0.18ab	17.776	<0.001
Contrast sensitivity					
A (3c/d)	4.44±0.77	4.36±0.76	3.84±1.11ab	3.335	0.041
B (6c/d)	5.04±1.17	5.04±1.14	4.12±1.48ab	4.357	0.016
C (12c/d)	6.24±2.07	5.16±1.65a	3.88±1.88ab	9.947	<0.001
D (18c/d)	6.44±1.78	5.28±2.01a	4.00±1.87ab	10.425	<0.001

Note: Compared with the cataract group, a P<0.05; with the PACG large pupil group, b P<0.05.

Table 3 Pearson Correlation Analysis of Pupil Size with S/R Ratio, Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Variable	Pupil Size	
	r	P
S/R	−0.075	0.525
Total aberration	0.373	0.001
Third-order aberration	0.229	0.048
Fourth-order aberration	0.273	0.018
Coma	0.367	0.001
Spherical	0.376	0.001

Pearson Correlation Analysis of Overall Contrast Sensitivity with S/R Ratio, Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson Correlation Analysis of Contrast Sensitivity a (3 c/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson correlation analysis revealed no significant correlation between contrast sensitivity A (3 c/d) and third-order aberration, fourth-order aberration, or coma aberration ($P > 0.05$). Contrast sensitivity A (3 c/d) was negatively correlated with total aberration and spherical aberration ($r = -0.201$ to -0.241, $P < 0.05$). See Table 4.

Pearson Correlation Analysis of Contrast Sensitivity B (6 c/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson correlation analysis revealed a significant negative correlation between contrast sensitivity B (6 c/d) and total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration ($r = -0.323$ to -0.439, $P = 0.005$ to <0.001). See Table 5.

Table 4 Pearson Correlation Analysis of Contrast Sensitivity a (3 c/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Variable	Contrast Sensitivity A	
	r	P
Total aberration	−0.241	0.037
Third-order aberration	−0.141	0.228
Fourth-order aberration	−0.245	0.054
Coma	−0.175	0.134
Spherical	−0.201	0.033

Table 5 Pearson Correlation Analysis of Contrast Sensitivity B (6 c/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Variable	Contrast Sensitivity B	
	r	P
Total aberration	−0.350	0.002
Third-order aberration	−0.323	0.005
Fourth-order aberration	−0.421	<0.001
Coma	−0.402	<0.001
Spherical	−0.439	<0.001

Pearson Correlation Analysis of Contrast Sensitivity C (12 C/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson correlation analysis revealed a significant negative correlation between contrast sensitivity C (12 c/d) and total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration ($r = -0.583$ to -0.397, $P < 0.001$). See Table 6.

Pearson Correlation Analysis of Contrast Sensitivity D (18 c/D) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Pearson correlation analysis revealed a significant negative correlation between contrast sensitivity D (18 c/d) and total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration ($r = -0.412$ to -0.582, $P < 0.001$). See Table 7.

Table 6 Pearson Correlation Analysis of Contrast Sensitivity C (12 C/d) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Variable	Contrast Sensitivity C	
	r	P
Total aberration	−0.481	<0.001
Third-order aberration	−0.397	<0.001
Fourth-order aberration	−0.487	<0.001
Coma	−0.521	<0.001
Spherical	−0.583	<0.001

Table 7 Pearson Correlation Analysis of Contrast Sensitivity D (18 c/D) with Total Aberration, Spherical Aberration, Coma Aberration, Third-Order Aberration, and Fourth-Order Aberration

Variable	**Contrast Sensitivity D**	
	r	**P**
Total aberration	−0.526	<0.001
Third-order aberration	−0.412	<0.001
Fourth-order aberration	−0.478	<0.001
Coma	−0.563	<0.001
Spherical	−0.582	<0.001

Table 8 Comparison of Visual Quality Questionnaire Scores Among the Three Patient Groups

Indicator	**Cataract (n=25)**	**PACG Normal Pupil (n=25)**	**PACG Large Pupil (n=25)**	**F**	**P**
Dryness	3.16±0.80	3.52±0.71	3.24±0.83	1.457	0.240
Visual fluctuations	1.80±0.82	2.00±0.87	2.12±0.78	0.967	0.385
Nighttime glare	2.28±0.98	2.48±0.87	3.48±0.77ab	13.401	<0.001
Halos	2.00±1.00	2.04±0.79	2.16±0.97	0.200	0.819
Difficulty driving at night	2.20±0.82	2.68±1.03	3.44±1.29ab	8.624	<0.001
Difficulty with fine tasks	3.08±0.91	3.08±0.91	3.04±1.06	0.014	0.986
Difficulty with prolonged reading	3.28±0.68	3.28±0.61	3.16±0.69	0.275	0.761
Visual satisfaction	4.16±0.75	4.32±0.69	4.28±0.74	0.085	0.919

Note: Compared with the cataract group, a P<0.05; with the PACG large pupil group, b P<0.05.

Visual Quality Questionnaire Scores Among the Three Patient Groups

One-way ANOVA revealed no statistically significant differences in scores for dryness, visual fluctuations, halos, difficulty with fine tasks, difficulty with prolonged reading, and visual satisfaction among the three patient groups ($P > 0.05$). However, the PACG large pupil group had higher scores for nighttime glare and difficulty driving at night compared to both the cataract group and the PACG normal pupil group ($P < 0.05$). See Table 8.

Discussion

Aberration refers to the deviation of the actual wavefront from the ideal wavefront. Aberrations are classified into higher-order and lower-order aberrations. Although lower-order aberrations (including myopia, hyperopia, astigmatism, etc) are more prevalent, they can be effectively corrected through cataract phacoemulsification, intraocular lens implantation, and angle closure surgery. In contrast, higher-order aberrations (including spherical aberration, coma, trefoil, and quadrupole) have become significant factors limiting retinal image quality. Research has shown that an increase in higher-order aberrations may lead to a decline in functional visual indicators (such as contrast sensitivity, MTF, point spread function (PSF), and S/R ratio), and can cause subjective visual discomfort symptoms like glare.[15,16] Correcting higher-order aberrations has been found to benefit visual indicators. Liang[17] et al demonstrated that adaptive optics correction of higher-order aberrations can improve contrast sensitivity. Guirao[18] calculated the theoretical visual improvement from complete correction of higher-order aberrations, revealing that even in normal populations without any retinal imaging quality abnormalities, correcting higher-order aberrations enhances visual quality.

In this study, we observed that pupil size is positively correlated with various ocular aberrations (including total aberration, third-order aberration, fourth-order aberration, coma aberration, and spherical aberration), with the strongest correlation observed with spherical aberration. This finding is consistent with previous research, which has indicated that when pupil diameter ≤ 4 mm, the level of higher-order aberrations is relatively low. However, as the pupil diameter increases, particularly when exceeding 7 mm, higher-order aberrations can increase significantly, with the RMS value of spherical aberration increasing by a factor of 1.94.[7] This phenomenon is attributed to spherical aberration arising from differences in light convergence ability between the central and peripheral regions of the lens. Normally, with a smaller pupil size, spherical aberration is relatively low. As the pupil diameter enlarges, more peripheral light from the cornea and lens enters the pupil, exposing a larger optical zone of the intraocular lens. The differing refractive powers of light at central and peripheral regions result in an increase in ocular spherical aberration.

The PACG normal pupil group, despite having a pupil diameter smaller than 5 mm similar to the cataract group, showed lower contrast sensitivity at 12 c/d and 18 c/d compared to the cataract group, even though there was no statistically significant difference in higher-order aberrations between the two groups. Additionally, in this study, the S/R ratio was higher in the cataract group compared to the PACG normal pupil group, though S/R ratio was not correlated with pupil size, which contradicts previous findings. Past research[19] has shown that after implanting an aspheric intraocular lens in cataract patients, the modulation transfer function cutoff, Strehl ratio, and OQAS values negatively correlate with pupil size as it increases from 2 to 6 mm. The S/R ratio reflects the impact of aberrations on the central light intensity of the image formed, representing the ratio of the actual optical system's (with aberrations) image to the ideal Gaussian point of an ideal optical system (without aberrations) at the same beam diameter.

In this study, although the average S/R ratio was higher in the PACG normal pupil group compared to the PACG large pupil group, the difference was not statistically significant. This may be due to the fact that early angle-closure glaucoma patients, even after surgical treatment and intraocular pressure normalization, may not show noticeable changes in central vision but might have experienced irreversible damage to certain latent visual functions. This could account for the lack of significant difference in S/R ratios between the groups and the reduced subjective visual perception, which aligns with some previous studies.[20]

This study also analyzed the correlation between contrast sensitivity at various spatial frequencies and different types of aberrations under low-light conditions. The results indicated that, under low-light conditions, only spherical aberration and total aberration were negatively correlated with contrast sensitivity at 3 c/d, 6 c/d, 12 c/d, and 18 c/d, while other aberrations were only negatively correlated with some frequencies of contrast sensitivity. Additionally, spherical aberration had a more significant impact on contrast sensitivity across all frequencies. This suggests that in the assessment of visual quality, spherical aberration and total higher-order aberrations play a dominant role. Higher overall ocular aberrations and spherical aberration are associated with lower contrast sensitivity and poorer visual quality. This finding is consistent with past literature,[21] which reported that spherical aberration and coma aberration significantly affect retinal imaging. Piers[22] and others have found that the optimal correction for spherical aberration is zero based on maximizing post-operative contrast sensitivity in cataract patients, while Beiko[23] found that a post-operative spherical aberration of +0.1 μm yielded the best contrast sensitivity. Thus, the optimal correction for spherical aberration remains unresolved.

In this study, the average spherical aberration in the PACG large pupil group was +0.47 μm, and it was significantly negatively correlated with contrast sensitivity at all frequencies. Additionally, the study shows a high correlation between pupil diameter and spherical aberration. It can be inferred that post-operative interventions to reduce pupil diameter in patients with early angle-closure glaucoma, who have not yet shown significant visual nerve damage or visual field loss, could directly affect visual quality. Thus, reducing the pupil diameter below 5 mm through techniques like pupil suturing can lower spherical aberration and significantly improve visual quality.

Moreover, whether all higher-order aberrations are detrimental to visual quality warrants discussion. Some literature[24,25] suggests that vertical coma aberration can enhance contrast sensitivity. However, this study did not differentiate between vertical and horizontal coma aberration, and data showed that coma aberration was negatively correlated with contrast sensitivity at 6 c/d, 12 c/d, and 18 c/d. Other studies[26] agree with this finding, suggesting that coma aberration significantly lowers visual quality. Therefore, the impact of coma aberration on visual quality deserves further discussion. In clinical practice, suturing the pupil in angle-closure glaucoma patients will directly affect multiple aberrations, and different changes in aberrations may have varying impacts on visual quality. It is essential to preserve beneficial aberrations to achieve better visual outcomes.

According to the NEI-RQL Chinese questionnaire results, this study found no statistically significant differences among the three groups regarding symptoms of dryness and the ability to read for extended periods, though scores were relatively high across the board. Previous reports[27] have suggested an association between cataract surgery and the onset or worsening of dry eye symptoms, with another study[28] noting that 35% of patients were dissatisfied with dry eye symptoms post-cataract surgery. For PACG patients, who may have more severe local inflammation due to elevated intraocular pressure and a poorer corneal surface environment, as well as longer combined surgery times, the impact on the ocular surface microenvironment is more pronounced. Some patients might experience prolonged dry eye symptoms due to disrupted ocular surface homeostasis post-surgery.

Additionally, the PACG large pupil group scored higher for nighttime glare and driving difficulties compared to the other two groups, with significant statistical differences. This finding aligns with the observed contrast sensitivity and higher-order aberrations in the PACG large pupil group, confirming that the loss of pupil constriction following acute angle-closure glaucoma can impact daily life despite restored central vision.

Although the PACG large pupil group had higher scores for these two indicators, there was no statistical difference in visual satisfaction scores among the three groups. This lack of difference may be due to the alleviation of long-term effects of high intraocular pressure and low vision following combined surgery, which might reduce post-operative visual discomfort. This suggests that visual satisfaction might also be influenced by psychological factors, preoperative visual quality, and postoperative visual demands, all of which could affect subjective perceptions of visual quality.

Conclusion

Pupil dilation is a significant issue following acute angle-closure glaucoma attacks, as it leads to various objective and subjective declines in visual quality, impacting postoperative quality of life. Even with reduced intraocular pressure and restored vision after surgery, many patients continue to experience complaints due to poor visual quality. This study confirms that patients with angle-closure glaucoma and a pupil diameter greater than 5 mm exhibit significantly increased higher-order aberrations, which severely affect subjective visual quality indicators such as contrast sensitivity. In clinical practice, methods like pupil suturing to reduce pupil diameter can improve visual quality for these patients.

Limitations and Future Directions

Unlike traditional glaucoma studies, this research combines glaucoma with optometry, offering a new perspective on refractive studies for early glaucoma patients. However, the study has limitations, such as a small sample size and insufficient indicators. The research only examined pupil diameter and various visual quality indicators in the same environment, which presents some constraints. Future studies could explore contrast sensitivity under different lighting conditions, such as bright light, low light, and glare, as well as near vision or near contrast sensitivity. Additionally, research could include angle-closure glaucoma patients without acute attacks and with smaller pupil diameters, expanding sample sizes and study durations, and evaluating the relationship between pupil diameter and postoperative retinal imaging quality to guide clinical practice.

Disclosure

The authors report no conflicts of interest in this work.

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