• Clinical Research •

Changes of pupil parameters and visual quality after cataract surgery as well as their correlation

Fan Yang[1,2,3], *Jie Xu*[1,2,3], *Pei–Min Lin*[1,2,3], *Ming–Yang Wang*[4,5,6], *Tian–Yu Zheng*[4,5,6]

[1]Eye Institute and Department of Ophthalmology, Eye & ENT Hospital, Fudan University, Shanghai 200031, China
[2]NHC Key Laboratory of Myopia and Related Eye Diseases, Shanghai 200031, China
[3]Shanghai Key Laboratory of Visual Impairment and Restoration, Shanghai 200031, China
[4]Department of Ophthalmology, Shanghai Tenth People's Hospital, Shanghai 200072, China
[5]Visual Rehabilitation Center, Tongji University School of Medicine, Shanghai 200072, China
[6]Tongji Eye Institute, Tongji University School of Medicine, Shanghai 200072, China
Co-first Authors: Fan Yang and Jie Xu
Correspondence to: Tian-Yu Zheng and Ming-Yang Wang. Department of Ophthalmology, Shanghai Tenth People's Hospital, Tongji University School of Medicine, Shanghai 200072, China. susu0102@163.com; wangmingyang@shsy11.wecom.work
Received: 2025-04-25 Accepted: 2026-04-27

Abstract
● **AIM:** To compare the changes of pupil parameters and visual quality after cataract surgery and explore their potential correlations.
● **METHODS:** This retrospective cohort study analyzed clinical data of Han Chinese patients who received cataract surgery from June 2016 to October 2016. Visual acuity, pupil size, pupil shift, wavefront aberrations, point spread function (PSF), and modulation transfer function (MTF) were detected preoperatively, 1d and 1mo postoperatively. Pupil parameters and visual outcomes were compared across the three time points.
● **RESULTS:** A total of 110 eyes from 110 patients (42 males and 68 females) were enrolled, with a mean age of 66.8±7.9y (range: 53–88y). Under both photopic and mesopic conditions, pupil diameter and pupil shift at 1d and 1mo after surgery were significantly lower than baseline levels. Corneal aberrations decreased postoperatively. Photopic and mesopic modulation transfer function derived from higher-order (HO) aberrations increased significantly from postoperative day 1 to postoperative month 1. Pupil size was positively correlated with wavefront aberrations, and negatively correlated with total PSF and HO-PSF. Significant correlations were identified between preoperative pupil diameter and 1-month postoperative visual quality indicators (including aberrations, PSF and modulation transfer function). A preoperative mesopic pupil diameter over 5.60 mm effectively predicted poor 1-month postoperative visual quality (HO aberrations >0.5 μm), with an area under the curve (AUC) of 0.71.
● **CONCLUSION:** Pupil parameters and visual quality alter significantly after cataract surgery, and moderate correlations exist between pupil diameter and visual quality at each time point. Preoperative pupil diameter is correlated with 1-month postoperative visual quality.
● **KEYWORDS:** aberrations; cataract surgery; modulation transfer function; point spread function; pupil diameter
DOI:10.18240/ijo.2026.08.09

Citation: Yang F, Xu J, Lin PM, Wang MY, Zheng TY. Changes of pupil parameters and visual quality after cataract surgery as well as their correlation. *Int J Ophthalmol* 2026;19(8):1518-1525

INTRODUCTION
With the development of cataract surgery techniques and the innovative design of intraocular lenses (IOLs), patients and surgeons are more focused on refractive correction and optimal visual quality than only regaining visual acuity. Wavefront aberrations play a key role in reducing the optimal visual quality[1]. Other metrics for quantifying visual quality have been proposed, such as the point spread function (PSF) and modulation transfer function (MTF)[2].

Previous studies have shown that the pupil diameter and shift are reduced after cataract surgery under both photopic and mesopic conditions[3-5]. The pupil plays an important role in visual function since its size directly affects field depth, retinal illuminance and so on[5]. For example, previous studies have shown that eyes with larger pupils are more likely to have greater aberrations and worse MTF[6-7]. Notably, pupil size is influenced by various factors, including age, sex, and anterior chamber depth[4-5].

In this study, we evaluated changes in pupil parameters and visual quality at preoperative, 1d, and 1mo postoperative time points, and explored the potential associations between pupil parameters and visual quality. Simultaneously, we analyzed the correlation between preoperative pupil parameters and postoperative visual outcomes to determine whether the former can be regarded as a predictor of the latter.

PARTICIPANTS AND METHODS

Ethical Approval This study was approved by the Ethics Committee of the Eye & ENT Hospital of Fudan University, Shanghai, China (ethical permit number: 2013021) and was conducted according to the principles of the Declaration of Helsinki. All participants provided written informed consent prior to their involvement in the study. No monetary compensation was provided to any participant.

Participants Han Chinese patients who underwent cataract surgery between June 2016 and October 2016 at the Eye & ENT Hospital of Fudan University were enrolled in this retrospective cohort study. The exclusion criteria were as follows: 1) patients who had previously undergone any ocular surgery; 2) patients with any intraoperative or postoperative complications; 3) patients with corneal edema during the early postoperative period; 4) patients with any other ocular pathology or neuropathy, including corneal disease, glaucoma, or trauma, that could reduce visual acuity. Patients with diabetes or high myopia who had fundus pathology were excluded. Patients for whom bilateral surgery was performed, only one eye, selected using a computer-generated random number table, was included in the final analysis to avoid inter-eye correlation bias.

Preoperative Examinations All the patients underwent basic ophthalmic examinations in the same fixed examination room with consistent indoor illumination conditions, including uncorrected distance visual acuity (UDVA; measured as the logarithm of the minimum angle of resolution, logMAR), corrected distance visual acuity (CDVA), slit-lamp microscopy, corneal topography (Pentacam HR; Oculus Optikgeräte, Wetzlar, Germany), and measurement with an IOL Master 700 (Carl Zeiss Meditec AG, Jena, Germany). The pupil data, including pupil size, PDist (distance between the photopic pupillary center and visual axis center), MDist (distance between the mesopic pupillary center and visual axis center), and MPDist (also called pupil shift, which refers to a shift in the pupil center from photopic to mesopic conditions), were measured by using an OPD-Scan III aberrometer (Nidek Co., Ltd., Gamagori, Japan) under photopic (125.6 lx) and mesopic (3.5 lx) conditions. Prior to measurements, the device was realigned and the subject was instructed to remain seated. The subject was then exposed to normal room lighting (56 lx) for 1min, followed by a 2-minute dark adaptation period with the examination room lights turned off (2 lx). OPD measurements were subsequently performed in the darkened room (2 lx). To ensure consistent illuminance across all measurements, a photometer was used to verify the ambient light level before each subject's assessment (relative indication error $\leq \pm 4\%$). Wavefront aberrations [total, higher-order aberrations (HOAs), coma-like, trefoil, and spherical aberrations and astigmatism] were measured with the same instrument. OPD-Scan III aberrometer's precision limits for measuring pupil diameter, pupil shift and visual quality parameters (aberrations, MTF and PSF) were 0.02, 1, and 0.001 mm, respectively. All the measurements were performed in the afternoon.

Surgical Procedure All surgeries were performed by an experienced doctor (Zheng TY) using the same procedure for all patients in the morning. A 2.3 mm clear corneal incision was made on the steep axis, which was marked preoperatively, followed by a 5.5 mm continuous curvilinear capsulorhexis. After performing standard phacoemulsification, the Tecnis ZCB00 (Johnson & Johnson, USA) was implanted in the capsular bag and centered relative to the visual axis. The Tecnis ZCB00 is an aspheric, hydrophobic acrylic, monofocal IOL with a negative spherical aberration, featuring a 6.0 mm optic diameter and C-loop haptics. After surgery, all the patients were treated with topical medications, including levofloxacin and prednisolone acetate four times a day for 2wk and pranoprofen four times a day for 4wk. Standard instructions for eye drop administration (at morning, noon, evening, and bedtime) were also provided.

Postoperative Follow-up The patient was followed up with postoperative examinations, including UDVA and CDVA, on the 1d and then 1mo after surgery in the afternoon. Prior to these follow-ups, all patients underwent routine slit-lamp examinations, and those with corneal edema were excluded from the study. OPD-Scan III was used to assess the pupil size, pupil shift, presence of wavefront aberrations, PSF and MTF, under conditions consistent with preoperative assessments. The MTF is provided as the area ratio, and the PSF is described using the Strehl ratio (SR). The MTF calculated from only HOAs [MTF (HO)] and the SR of PSF (HO) values were retrieved from only HOAs corresponding to the MTF and SR values with the correction of refractive errors. The root mean square values for aberrations were calculated and recorded for all pupils with small and large diameters as they changed under photopic or mesopic conditions. It is worth noting that none of the patients received mydriatic eye drops within 24h prior to the postoperative examinations.

Statistical Analysis All continuous data are presented as the mean±standard deviations. One-way repeated-measures analysis of variance with a Bonferroni post hoc correction was applied to compare the pupil parameters and visual quality at different time points. A paired *t*-test was applied to compare visual quality between 1d and 1mo after surgery. Pearson's correlation was used to analyze the relationships between pupil size and pupil shift and between pupil data and visual quality. Power analysis and sample size software were used to calculate the sample size. Sample size calculation was performed for the primary endpoint of photopic diameter, measured at three repeated time points. With assumed means of 3.73, 2.74, and 3.05 across the time points, a standard deviation of 1.7, a two-sided α of 0.05, and a power of 0.90, a minimum of 38 subjects per time point was required to ensure adequate statistical power.

A receiver operating characteristic (ROC) curve was constructed to assess the relationship between preoperative mesopic pupil diameter and worse 1mo postoperative visual quality (total HOAs >0.5 μm). The area under the curve (AUC) was used to evaluate the diagnostic performance of the preoperative mesopic pupil diameter in predicting 1mo postoperative visual quality. Youden's index (YI) was calculated using the formula: YI=sensitivity+specificity–1. The cutoff point for the preoperative mesopic pupil diameter was determined based on the maximum YI.

All *P* values were 2-sided, and a *P* value <0.05 was considered statistically significant. Statistical analysis was performed using SPSS version 25.

RESULTS

Changes in Pupil Parameters In total, the final sample in the study was composed of 110 eyes of 110 patients (42 men, 68 women). The age range of the patients was 53–88y, and the mean age of the patients was 66.8±7.9y.

The mean preoperative photopic and mesopic pupil diameters were 3.73±1.21 and 5.65±1.07 mm, respectively. The mean photopic and mesopic pupil diameters on postoperative day 1 were 2.74±0.41 and 4.28±0.74 mm, respectively. The mean photopic and mesopic pupil diameters at 1mo postoperatively were 3.05±0.53 and 4.73±0.85 mm, respectively (Figure 1). The photopic and mesopic pupil sizes at 1d postoperatively were significantly smaller than the baseline values [photopic: mean difference=0.98; 95% confidence intervals (CI; 0.77, 1.19); Cohen's *d*=0.88; mesopic: mean difference=1.37; 95%CI (1.20, 1.54); Cohen's *d*=1.53; both *P*<0.001]. The photopic and mesopic pupil sizes at 1mo postoperatively were also significantly smaller than the baseline values [photopic: mean difference=0.68; 95%CI (0.45, 0.91); Cohen's *d*=0.56; mesopic: mean difference=0.92; 95%CI (0.73, 1.10); Cohen's *d*=0.92; both *P*<0.001]. Significant differences were also observed between 1d and 1mo after cataract surgery under both photopic and mesopic conditions [photopic: mean difference=-0.31; 95%CI (-0.37, -0.25); Cohen's *d*=-0.98; mesopic: mean difference=-0.45; 95%CI (-0.56, -0.35); Cohen's *d*=-0.81; both *P*<0.001)]. Our results indicated that the pupil diameter decreased under both photopic and mesopic conditions after surgery and was partially restored at 1mo after surgery but was not restored to the preoperative level.

The mean preoperative, 1d and 1mo postoperative PDist values were 0.25±0.14, 0.24±0.13, and 0.21±0.13, respectively (Figure 2). The PDist decreased after cataract surgery and continued to decrease for 1mo. The differences between before and 1mo after surgery [mean difference=0.04; 95%CI (0.01, 0.06); Cohen's *d*=0.30; *P*=0.007] and between 1d and 1mo after surgery [mean difference=0.03; 95%CI (0.01, 0.05); Cohen's *d*=0.35; *P*=0.001] were statistically significant, whereas the difference between before surgery and 1d after

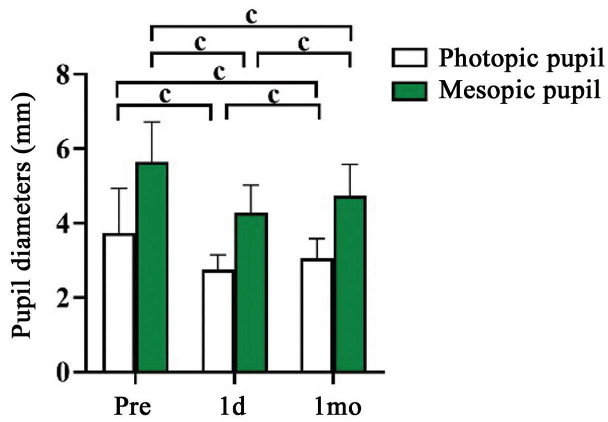

Figure 1 Pupil diameter under photopic and mesopic conditions Pupil diameter under photopic and mesopic conditions at each time point. [c]*P*<0.001 between the 2 time points. The error bars represent the standard deviation of the mean value. Pre: Before cataract surgery; 1d: 1d after cataract surgery; 1mo: 1mo after cataract surgery.

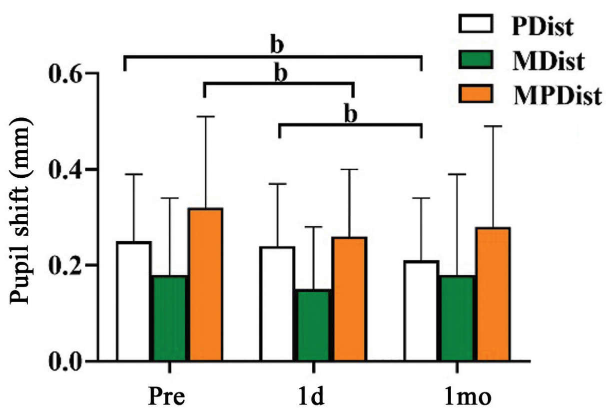

Figure 2 PDist, MDist, and MPDist under photopic and mesopic conditions [b]*P*<0.01 between the 2 time points. The error bars represent the standard deviation of the mean value. PDist: Distance between the photopic pupillary center and visual axis center; MDist: Distance between the mesopic pupillary center and visual axis center; MPDist: A shift in pupil center from photopic to mesopic conditions; Pre: Before cataract surgery; 1d: 1d after cataract surgery; 1mo: 1mo after cataract surgery.

surgery was not statistically significant (P=1.000). The mean preoperative, 1d and 1mo postoperative MDist values were 0.18±0.16, 0.15±0.13, and 0.18±0.21, respectively. The MDist decreased after surgery and increased from 1d to 1mo after surgery. However, the differences between before and 1d after (P=0.405) and 1d after and 1mo after (P=0.566) were not statistically significant. The mean preoperative, 1d and 1mo postoperative MPDist values were 0.32±0.19, 0.26±0.14 and 0.28±0.21, respectively. Significant differences were observed between the preoperative and 1d postoperative values [mean difference=0.06; 95%CI (0.02, 0.10); Cohen's d=0.29; P=0.008], whereas the slight decrease between the preoperative and 1mo postoperative values and a slight increase between the 1d and 1mo postoperative values were not statistically significant (P=0.375 and P=0.709, respectively).

Correlations Between Different Pupil Parameters There was a correlation between pupil size before and after surgery. Larger photopic pupils preoperatively tended to be larger 1d and 1mo postoperatively [Pearson's correlation coefficient r=0.387 and r=0.202, respectively, both P<0.05), as did mesopic pupils (r=0.559 and r=0.485, respectively, both P<0.05)]. There was also a correlation between the 1d and 1mo postoperative values (photopic r=0.808, mesopic r=0.762, respectively; both P<0.001). Moreover, there was a certain correlation between photopic and mesopic pupil size at every time point (r=0.767, 0.672, and 0.830, respectively; all P<0.001).

We also noted that both the PDist and MPDist were positively correlated with the preoperative and 1d postoperative values, the preoperative and 1mo postoperative values, and the 1d and 1mo postoperative values (PDist: r=0.596, r=0.578, r=0.784, respectively; MPDist: r=0.196, r=0.217, r=0.283, respectively; all P<0.05). No significant differences were found in the MDist between the preoperative and 1d postoperative values (P=0.444), between the preoperative and 1mo postoperative values (P=0.066), or between the 1d and 1mo postoperative values (P=0.058). There was a correlation between photopic pupil size and PDist at 1d and 1mo after cataract surgery (r=0.190, P=0.047; r=0.259, P=0.006, respectively), but there was no correlation between mesopic pupil size and MDist at 1d or 1mo after surgery (P=0.492, P=0.600, respectively). We also found correlations between photopic pupil size and MPDist at 1mo after surgery (r=0.237, P=0.013). Both the PDist and the MDist were correlated with the MPDist at each time point (pre, r=0.576, r=0.605; 1d, r=0.478, r=0.290; 1mo, r=0.478, r=0.693, respectively, all P<0.05).

Changes in Visual Quality The mean preoperative UDVA and 1mo postoperative UDVA of the patients were 0.89±0.40 and 0.22±0.24 logMAR, respectively. The CDVAs were 0.75±0.39 and 0.04±0.12 logMAR, respectively. Cataract surgery statistically improved both the UDVA [mean difference=0.67; 95%CI (0.59, 0.74); Cohen's d=1.60; P<0.001] and the CDVA [mean difference=0.71; 95%CI (0.63, 0.78); Cohen's d=1.76; P<0.001].

We found that corneal aberrations were decreased after cataract surgery in both photopic (Figure 3A) and mesopic (Figure 3B) states. For 1d postoperative aberrations, the total, coma and spherical aberrations and astigmatism were significantly lower than the preoperative values under both photopic and mesopic states (all P<0.05), and the HOAs were significantly lower than the preoperative values under mesopic states (all P<0.05). The total, HOA, coma and spherical aberrations and astigmatism were significantly lower at 1mo after cataract surgery than before surgery in both the photopic and mesopic states, and trefoil aberrations were significantly lower at 1mo after cataract surgery than before surgery in the photopic state (all P<0.05). Compared with those at 1d after cataract surgery, trefoil aberrations under photopic conditions decreased, and spherical aberrations under mesopic conditions increased significantly at 1mo after cataract surgery (all P<0.05). No difference was found in terms of intraocular aberrations from 1d to 1mo after cataract surgery under photopic conditions (Figure 3C), whereas intraocular spherical aberrations increased from 1d to 1mo after cataract surgery under mesopic conditions (P=0.004; Figure 3D). No difference was found in terms of ocular aberrations from 1d to 1mo after cataract surgery (Figure 3E), whereas spherical aberrations increased from 1d to 1mo after cataract surgery under mesopic conditions (P=0.030; Figure 3F).

A comparison of the total MTF and MTF (HO) between 1d and 1mo after cataract surgery at different spatial frequencies under photopic and mesopic conditions is provided in Figure 4. No statistically significant differences were detected in the total MTF at 1mo after surgery compared with that at 1d after surgery at any spatial frequency, except 5 cycles per degree (cpd) under photopic conditions (Figure 4A, 4B). MTF (HO) demonstrated significantly greater performance at all spatial frequencies under photopic conditions at 1mo after cataract surgery than at 1d (Figure 4C). Additionally, MTF (HO) showed significantly enhanced performance at 5, 10, 15, and 50 cpd under mesopic conditions at 1mo after cataract surgery compared to 1d after surgery (Figure 4D).

The SRs of the total PSF and PSF (HO) at both 1d and 1mo after cataract surgery under photopic and mesopic conditions are presented in Table 1. No differences were detected in the PSF or PSF (HO) between 1d and 1mo after surgery.

Correlation Between Pupil Parameters and Visual Quality We analyzed the relationships between the pupil parameters and visual quality at each time point. At 1d after cataract surgery, photopic and mesopic pupil sizes were positively correlated with ocular and corneal aberrations (all P<0.05).

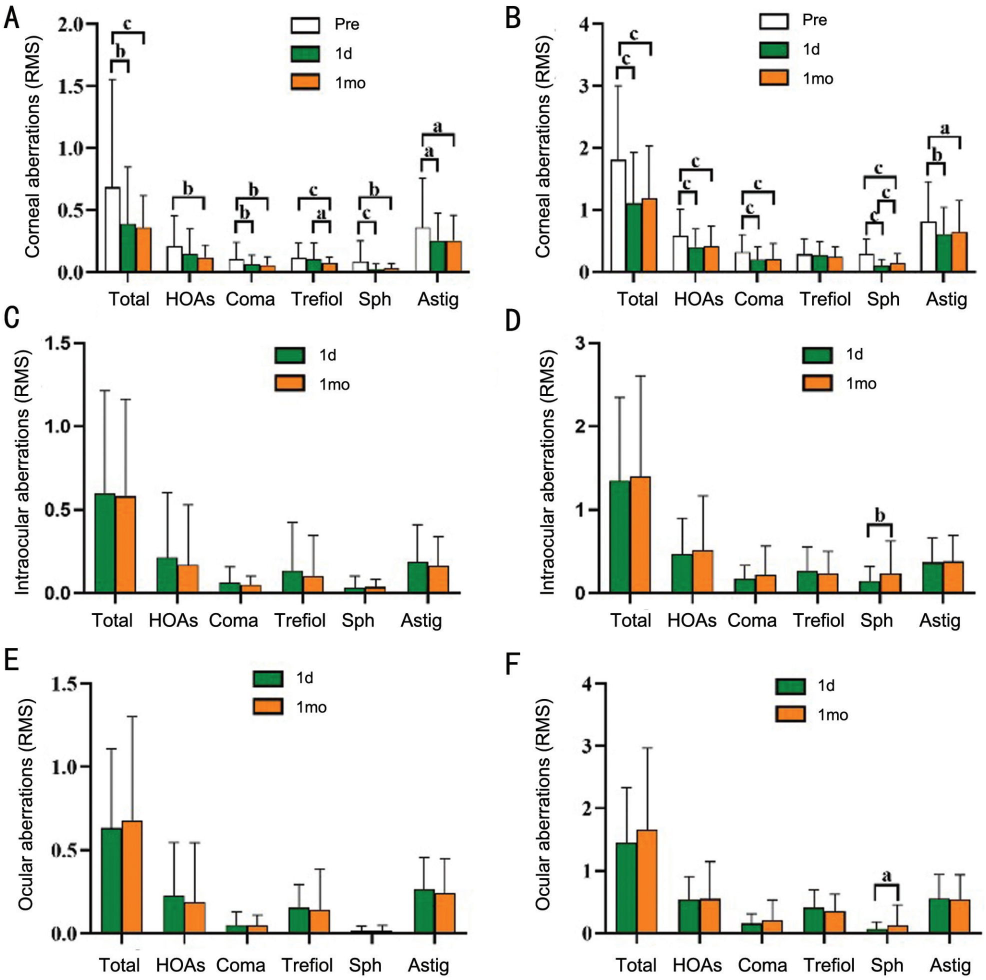

Figure 3 Corneal, intraocular and ocular aberrations Corneal (A, B), intraocular (C, D), and ocular (E, F) aberrations under photopic (A, C, E) and mesopic (B, D, F) conditions at each time point. A significant difference was found between the 2 time points ([a]$P<0.05$, [b]$P<0.01$, [c]$P<0.001$). The error bars represent the standard deviation of the mean value. Total: Total aberrations; HOAs: Higher-order aberrations; Coma: Coma-like aberrations; Trefoil: Trefoil aberrations; Sph: Spherical aberrations; Astig: Astigmatism; RMS: Root mean square; Pre: Before cataract surgery; 1d: 1d after cataract surgery; 1mo: 1mo after cataract surgery.

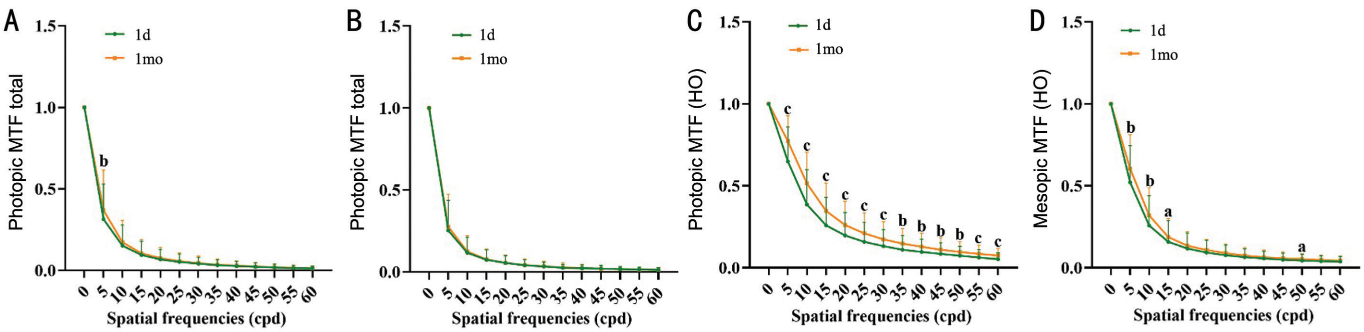

Figure 4 Total MTF and MTF (HO) under photopic and mesopic conditions at each time point A significant difference was found between the 2 time points ([a]$P<0.05$, [b]$P<0.01$, [c]$P<0.001$). The error bars represent the standard deviation of the mean value. MTF: Modulation transfer function; MTF (HO): HOAs corresponding to the modulation transfer function; 1d: 1d after cataract surgery; 1mo: 1mo after cataract surgery.

Intraocular aberrations, except trefoil aberrations in the mesopic condition (P=0.375), were positively correlated with pupil size in the corresponding condition (all $P<0.05$). Photopic and mesopic pupil sizes were negatively correlated with total PSF and PSF (HO) in the corresponding condition (all $P<0.05$). Then, we analyzed the correlation between the pupil size and the MTF and MTF (HO) at all spatial frequencies from 5 to 60 cpd (every 5 cpd). Mesopic pupil size was significantly negatively correlated with MTF (HO) at spatial frequencies of 10, 15, 20, 25, 30, 35, 40, and 45 cpd (all $P<0.05$). Photopic pupil size had no significant correlation with MTF or MTF (HO) at any of the spatial frequencies (all $P>0.05$).

At 1mo after cataract surgery, photopic pupil size was positively correlated with UDVA (logMAR, P=0.023). Photopic and mesopic pupil sizes were positively correlated with ocular and corneal aberrations (all P<0.05). Intraocular aberrations, except trefoil aberrations in the photopic condition (P=0.158), were positively correlated with pupil size in the corresponding condition (all P<0.05). Similar to 1d after cataract surgery, photopic and mesopic pupil sizes were negatively correlated with total PSF and PSF (HO) in the corresponding conditions (all P<0.05). Photopic pupil size was significantly negatively correlated with MTF at a spatial frequency of 5 cpd (P<0.05) but not significantly correlated with MTF (HO) at any of the spatial frequencies. Mesopic pupil size was significantly negatively correlated with MTF at spatial frequencies of 5, 10, 15, 20, 25, 30, 35, and 50 cpd and with MTF (HO) at all spatial frequencies (all P<0.05).

Preoperative Pupil Data as a Correlated Factor for 1mo Postoperative Visual Quality To determine whether preoperative pupil data can serve as a correlated factor of postoperative visual quality, factors including preoperative pupil size and pupil shift were analyzed for their associations with 1mo postoperative visual quality. There was a significant positive correlation between preoperative mesopic pupils and postoperative ocular aberrations (total, r=0.258, HOAs, r=0.316, coma, r=0.317, spherical, r=0.322, all P<0.05), corneal aberrations (total, r=0.275, HOAs, r=0.230, trefoil, r=0.228, spherical, r=0.301, astigmatism, r=0.218, all P<0.05), and intraocular aberrations (total, r=0.313, HOAs, r=0.326, coma, r=0.303, spherical, r=0.364, astigmatism, r=0.193, all P<0.05). There was a significant negative correlation between preoperative pupil size and postoperative PSF (HO; photopic r=-0.258, mesopic r=-0.290, both P<0.05). There was a significant negative correlation between preoperative mesopic pupil size and postoperative MTF (HO; 5 cpd, r=-0.264, 10 cpd, r=-0.233, 15 cpd, r=-0.254, 20 cpd, r=-0.255, 25 cpd, r=-0.222, 30 cpd, r=-0.203, 50 cpd, r=-0.195, 55 cpd, r=-0.225, 60 cpd, r=-0.202, all P<0.05).

Given the significant correlation between preoperative mesopic pupil diameter and postoperative aberrations, we constructed an ROC curve to assess the diagnostic performance of preoperative mesopic pupil diameter in predicting 1mo postoperative visual quality deterioration (Figure 5). The AUC was 0.71 (95%CI=0.61–0.81; P<0.001). The maximum YI value of 0.38 corresponded to a preoperative mesopic pupil diameter of 5.60 mm. At this cutoff, the sensitivity and specificity for predicting 1mo postoperative visual quality deterioration (total HOAs >0.5 μm) were 0.76 and 0.62, respectively.

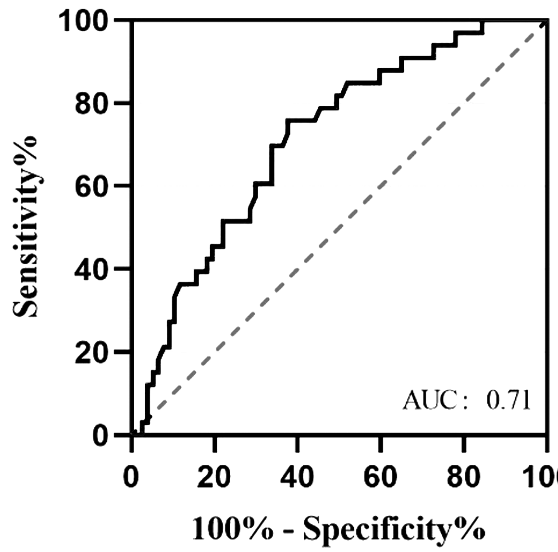

Figure 5 Receiver operating characteristic curve illustrating the diagnostic performance of preoperative mesopic pupil diameter in predicting 1mo postoperative visual quality deterioration Total higher-order aberrations >0.5 μm.

Table 1 Comparison of the Strehl ratios of total PSF and PSF (HO) at 1d and 1mo after cataract surgery

Variable	1d after cataract surgery	1mo after cataract surgery	P
SR of photopic PSF	0.062±0.068	0.061±0.069	0.925
SR of photopic PSF (HO)	0.271±0.216	0.313±0.212	0.113
SR of mesopic PSF	0.022±0.027	0.020±0.023	0.396
SR of mesopic PSF (HO)	0.071±0.082	0.074±0.062	0.769

PSF: Point spread function; HO: Calculated from only higher-order aberrations; SR: Strehl ratio.

DISCUSSION

Similar to previous studies[3-5], the pupil diameter decreased 1d after cataract surgery and then recovered gradually, but the diameter had not recovered to baseline when it was measured at 1mo after surgery. In a previous study, the reason for the decrease was the increased depth and volume of the anterior chamber and the free movement of the constrictor iris muscles and their more flexible response to illumination after the extraction of bulky and turbid lenses[3]. On the other hand, it is possible that the sphincter pupillae muscle contracted because of stimulation during surgery.

We evaluated the relationships between the pupil parameters and visual outcomes at each time point. After cataract surgery, in general, pupil size was positively associated with aberrations at 1d and 1mo under both photopic and mesopic conditions. Many studies have reported that a larger pupil size is associated with increased ocular aberrations[6,8-10]. Corneal aberrations, especially corneal spherical aberrations, are positively correlated with pupil size[11-12]. Visual quality may change from day to night in patients who have undergone cataract surgery due to the change in pupil size and its effect on wavefront aberrations, especially HOAs.

Moreover, pupil size was negatively associated with PSF and PSF (HO) at 1d and 1mo under both photopic and mesopic conditions. Watson[13] plotted mean radial MTFs at various pupil diameters and reported that the mean MTFs decreased as the pupil diameter increased at low and medium spatial frequencies. Our findings concur in that there are negative associations between pupil diameters and MTFs, and the related coefficients are generally greater at low and medium spatial frequencies than at high spatial frequencies.

Compared with those at baseline, corneal aberration decreased at 1d and 1mo under both photopic and mesopic conditions overall. The results of other studies concerning corneal aberration changes due to incisions are controversial. A previous study indicated that corneal and internal aberrations were greater in those who received cataract surgeries than in those in the control group because of a loss of balance of internal and corneal spherical aberrations, aberration of the IOL, and tilt and centration of the IOL[14]. In the present study, we hypothesize that the decrease in corneal aberrations may be related to the type of surgical incision used. The incision, made on the steep axis in each patient, could potentially explain the reduction in corneal aberrations and astigmatism. A previous study revealed that patients with steep-axis incisions have significantly less corneal astigmatism and better visual quality, such as HOAs, MTF, and PSF, than do those with nonsteep-axis incisions[15]. The intraocular spherical aberrations and total ocular aberrations increased from 1d to 1mo after surgery. It can be hypothesized that the change is attributable to the increase in pupil diameter during the same period. A previous study noted that the diffuse spot centered on the optical axis becomes larger as the pupil dilates, which leads to worse visual quality[11].

We found that MTF (HO) significantly increased, while no significant difference was observed in total MTF (except at 5 cpd under photopic conditions) from 1d to 1mo postoperatively. The improvement in MTF (HO) may be due to the stabilization of the IOL, which decreased HOAs[16-17]. However, residual astigmatism and scatter likely prevented significant improvement in total MTF. This indicates that while HOAs improved, lower-order aberrations or scatter may have remained unchanged[18].

Although HOAs decreased, both PSF (HO) and total PSF remained unchanged from 1d to 1mo. This may be due to the dominant effect of lower-order aberrations on the Strehl ratio, where minor changes in HOAs have minimal impact when lower-order aberrations are not fully corrected[19]. Despite a reduction in HOAs, residual astigmatism and scatter persisted.

Our results revealed that preoperative mesopic pupil size was positively correlated with postoperative ocular, corneal and intraocular aberrations and negatively correlated with PSF (HO) and MTF (HO). Preoperative photopic pupil size was negatively correlated with postoperative PSF (HO). This means that patients with larger preoperative mesopic pupil diameters tend to have greater aberrations, worse PSF (HO) and worse MTF (HO) after cataract surgery, and larger preoperative photopic pupil sizes are also related to worse postoperative PSF (HO). An ROC curve analysis demonstrated moderate diagnostic performance (AUC=0.71). The optimal cutoff for predicting 1mo postoperative visual quality deterioration (total HOAs >0.5 μm) was a preoperative mesopic pupil diameter of 5.60 mm, with a sensitivity of 0.76 and specificity of 0.62. This suggests that preoperative mesopic pupil diameter can be regarded as a correlated factor of 1mo postoperative visual outcomes.

In summary, pupil parameters, especially the pupil diameter, are important in cataract surgery. Pupil size and pupil shift decreased after cataract surgery compared with baseline under both photopic and mesopic conditions. Considering the moderate correlations between the pupil parameters and visual quality, we suggest that the preoperative pupil diameter may be regarded as a correlated factor of 1mo postoperative visual quality, including aberrations, PSF and MTF.

ACKNOWLEDGEMENTS

Authors' Contributions: Yang F: Writing-original draft, data curation, formal analysis, methodology. Xu J: Investigation, data curation, writing-original draft, conceptualization. Lin PM: Investigation, data curation, software. Wang MY: Writing-review & editing, supervision, conceptualization. Zheng TY: Writing-review & editing, supervision, project administration, funding. All authors read and approved the final manuscript.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

AI-Generated Content Disclosure: The authors declare that no Artificial Intelligence Content Generation (AICG) tools, including large language models, generative AI algorithms, or AI-assisted writing, analysis, visualization, and coding tools, were used at any stage of this manuscript. All content was independently conceived, developed, and verified by the authors.

Foundations: Supported by National Natural Science Foundation of China (No.81300747); Natural Science Foundation of Shanghai (Science and Technology Commission of Shanghai Municipality, No.22ZR1410400; No.19ZR1408600); the Excellent Young Doctor Training Program of Shanghai (Shanghai Municipal Health Commission, No.2015-2018); the Clinical Research Project of Shanghai Municipal Health Commission (Shanghai Municipal Health Commission, No.202540103); the Shanghai Municipal Health Commission's Seed Program for Medical New Technology Research and Translation (Shanghai Municipal Health Commission, No.2025ZZ2068);

the Scientific Research Program of Shanghai Pudong New Area Health Commission (Shanghai Pudong New Area Health Commission, No.PW2024D-05); Young Clinical Scientist Training Program (Fudan University Shanghai Medical College, No.DGF828019-2/038); the "Medicine+X" Interdisciplinary Research Project (Tongji University, No.2025-0553-YB-07); Vision and Action-Ophthalmology Clinical Research Support Program (the Bethune Foundation, No.BFC-KECS-LC-20251022-01); Shanghai Tenth People's Hospital Undergraduate Teaching Courses (Tenth People's Hospital of Tongji University, Funding Type: A: 2025 Blended Teaching Courses and B: 2025 Demonstration Courses).

Conflicts of Interest: Yang F, None; **Xu J,** None; **Lin PM,** None; **Wang MY,** None; **Zheng TY,** None.

REFERENCES

1 Wang Y, Zang B, Bi QL, *et al*. Impact of intraocular lens decentration and tilt on higher-order aberrations in patients with high and super-high myopia following cataract surgery. *Indian J Ophthalmol* 2025;73(7):993-999.

2 Xu J, Yang F, Lin PM, *et al*. Biometric factors associated with the postoperative visual performance of a multifocal intraocular lens. *Heliyon* 2024;10(11):e31867.

3 Kanellopoulos AJ, Asimellis G, Georgiadou S. Digital pupillometry and centroid shift changes after cataract surgery. *J Cataract Refract Surg* 2015;41(2):408-414.

4 Ordiñaga-Monreal E, Castanera-Gratacós D, Castanera F, *et al*. Pupil size differences between female and male patients after cataract surgery. *J Optom* 2022;15(2):179-185.

5 Kanellopoulos AJ, Asimellis G. Clear-cornea cataract surgery: pupil size and shape changes, along with anterior chamber volume and depth changes. A Scheimpflug imaging study. *Clin Ophthalmol* 2014;8:2141-2150.

6 Stern B, Gatinel D. Impact of pupil size and corneal spherical aberrations on the performance of monofocal intraocular lenses: an experimental model. *Biomed Opt Express* 2024;15(11):6433-6448.

7 Ukai Y, Mito T, Nakatsugawa Y, *et al*. Risk factors for photic phenomena in two different multifocal diffractive intraocular lenses. *Sci Rep* 2025;15:121.

8 Bansal M, Thakur A, Jeshan M, *et al*. Visual and clinical outcomes after bilateral implantation of a novel extended depth of focus lens post cataract surgery. *Indian J Ophthalmol* 2024;72(9):1267-1274.

9 Ashena Z, Gallagher S, Naveed H, *et al*. Comparison of anterior corneal aberrometry, keratometry and pupil size with scheimpflug tomography and ray tracing aberrometer. *Vision* (*Basel*) 2022;6(1):18.

10 McKelvie J, McArdle B, McGhee C. The influence of tilt, decentration, and pupil size on the higher-order aberration profile of aspheric intraocular lenses. *Ophthalmology* 2011;118(9):1724-1731.

11 Liao X, Wang MJ, Tan QQ, *et al*. Repeatability of i.Profiler for measuring wavefront aberrations in healthy eyes. *Int Ophthalmol* 2022;42(8):2525-2531.

12 Petermeier K, Frank C, Gekeler F, *et al*. Influence of the pupil size on visual quality and spherical aberration after implantation of the Tecnis 1-piece intraocular lens. *Br J Ophthalmol* 2011;95(1):42-45.

13 Watson AB. A formula for the mean human optical modulation transfer function as a function of pupil size. *J Vis* 2013;13(6):18.

14 Marcos S. Are changes in ocular aberrations with age a significant problem for refractive surgery? *J Refract Surg* 2002;18(5).

15 He WW, Zhu XJ, Du Y, *et al*. Clinical efficacy of implantation of toric intraocular lenses with different incision positions: a comparative study of steep-axis incision and non-steep-axis incision. *BMC Ophthalmol* 2017;17(1):132.

16 Jing DL, Jiang XD, Ren XT, *et al*. Change patterns in corneal intrinsic aberrations and nerve density after cataract surgery in patients with dry eye disease. *J Clin Med* 2022;11(19):5697.

17 Li HZ, Cen JY, Tong WT, *et al*. Intraocular lens tilt and decentration and optical quality after primary intraocular lens implantation in pediatric cataract patients. *Adv Ophthalmol Pract Res* 2025;5(4):285-292.

18 Zhang LM, Shen WQ, Shen JY, *et al*. Effect of postoperative residual astigmatism on visual outcomes after trifocal intraocular lens implantation. *Front Med (Lausanne)* 2023;10:1202793.

19 Hirohara Y, Mihashi T, Koh S, *et al*. Optical quality of the eye degraded by time-varying wavefront aberrations with tear film dynamics. *Jpn J Ophthalmol* 2007;51(4):258-264.