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Research article

Biometric factors associated with the postoperative visual performance of a multifocal intraocular lens

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ABSTRACT

Purpose: To identify the biometric factors associated with postoperative visual performance after uneventful phacoemulsification with multifocal intraocular lens (MIOL) implantation.
Methods: In this retrospective cohort study, 72 eyes of 72 patients implanted with the Human-Optics Diff-aAY MIOL were included. Preoperative examination data including the white-to-white distance (WTW), anterior chamber depth (ACD), axial length and corneal astigmatism were gathered through the electronic medical records. One month postoperatively, the pupil parameters, corneal aberrations, corneal astigmatism, IOL tilts and IOL decentrations were measured using an OPD-Scan III aberrometer. Postoperative visual performance parameters were recorded as the visual acuity, depth of focus, modulation transfer function (MTF) and point spread function (PSF) values, area under log contrast sensitivity function (AULCSF), retinal straylight and visual function questionnaire scores. Univariate and multivariate linear regression analyses were then performed to evaluate the associations between the potential biometric factors and postoperative visual outcomes.
Results: Younger age predicted greater MTF and PSF values, better AULCSF and better retinal straylight ($P < 0.05$). A lower corneal trefoil predicted better MTF and PSF values ($P < 0.05$). Smaller IOL decentration predicted better distance-corrected near visual acuity, greater AULCSF and better retinal straylight ($P < 0.05$). A less negative spherical equivalent (SE) predicted better MTF values ($P = 0.017$), while a more negative SE predicted better Visual Function Index-14 (VF-14) questionnaire scores and satisfaction scores ($P < 0.05$). A higher IOL power predicted better best corrected distance visual acuity ($P = 0.005$). Lower preoperative corneal astigmatism predicted greater MTF values ($P = 0.020$). Lower postoperative corneal astigmatism, smaller corneal high-order aberrations (HOAs), smaller photopic pupil size, larger WTW and deeper ACD predicted a better AULCSF ($P < 0.05$).
Conclusions: IOL decentration, IOL power, age, preoperative and postoperative corneal astigmatism, SE, photopic pupil size, corneal trefoil, WTW, ACD and corneal HOAs were significantly associated with postoperative visual performance. These findings might aid in patient selection prior to MIOL implantation.

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1. Introduction

Recently, multifocal intraocular lens (MIOL) implantation has become an increasingly common solution for patients who pursue spectacle independence after cataract surgery. Although the MIOL design has been greatly improved, substantial uncertainty remains in the prediction of visual outcomes for individual patients with MIOL implantation. Postoperative visual performance does not always meet preoperative expectations [1–3]. Some patients complain of less than satisfactory performance for near vision, some patients have disturbing ocular symptoms (e.g., glare and halos), and some patients report optical difficulties such as decreased contrast sensitivity [1–3].

According to the current knowledge, not all patients will benefit equally from MIOL implantation; hence, careful patient selection and identification of the factors characterizing good MIOL candidates are vital. Consequently, knowing the factors influencing postoperative visual performance in advance may help in choosing the appropriate MIOL for each patient. Although it has been previously reported that pupil size [4], angle κ [5], angle α [6], corneal astigmatism [7], high-order aberrations (HOAs) [8] and IOL decentration [9,10] may affect the postoperative visual performance achieved with a specific MIOL, limited scientific evidence is available. Furthermore, few studies in the published literature have evaluated the role of age, IOL power, white-to-white distance (WTW), anterior chamber depth (ACD), axial length (AL), or pupil center shift from photopic to mesopic conditions (MPDist) as specific predictors of patient outcomes. In addition, previous studies have not addressed overall postoperative visual performance parameters, including visual acuity, depth of focus, objective and subjective visual quality, or dysphotopsia symptoms.

Therefore, in this study, we evaluated distance and near visual acuity, depth of focus, modulation transfer function (MTF), point spread function (PSF), contrast sensitivity, retinal straylight, Visual Function Index-14 (VF-14) questionnaire scores, and patient satisfaction after MIOL implantation. We also sought to systematically analyze the pre- and postoperative biometric factors correlated with these postoperative visual performance parameters and evaluate their effects on patient outcomes.

2. Methods

2.1. Patients

This retrospective cohort study was conducted at the Eye and ENT Hospital of Fudan University. It was approved by the ethics committee of the Eye and ENT Hospital of Fudan University and was carried out according to the principles of the Declaration of Helsinki. From January 2022 to January 2023, a total of 91 patients (102 eyes) underwent phacoemulsification with implantation of a diffractive MIOL with +3.50 near addition (Diff-aAY, HumanOptics AG, Erlangen, Germany) by one experienced surgeon (TYZ). This diffractive MIOL has a 6.0 mm optic that consists of a central 3.5 mm diffractive zone and an outer refractive zone. The diffractive structure of the MIOL is composed of 9 diffractive circular steps: the central diffractive ring diameter is 1.2 mm, the first 3 steps are of the same height, and there is a gradual decrease in the 6 remaining step heights, creating a smooth transition to distance-dominant vision as the pupil enlarges.

The inclusion criteria were age between 40 and 90 y and the ability to communicate clearly. The exclusion criteria were a history of ocular surgery; intraoperative or postoperative complications; and other ocular pathology or neurological lesions that might affect postoperative visual performance, such as corneal disease, ocular trauma, lens subluxation, uveitis, glaucoma, retinopathy and amblyopia. Patients who did not participate in the postoperative follow-up were also excluded from this investigation. If both eyes met the inclusion criteria, the first operated eye was registered. Finally, 72 patients (72 eyes) were included in our analysis. All patients provided written informed consent.

2.2. Recording of preoperative examination data

Preoperative examination data were gathered through the use of electronic medical records. Preoperatively, all patients underwent comprehensive ophthalmologic examinations, including measurements of visual acuity, slit-lamp microscopy, and B-mode ultrasound. The WTW diameter (indicating the horizontal corneal diameter) was measured between the borders of the corneal limbus using an IOLMaster 500 optical biometer (Carl Zeiss AG, Oberkochen, Germany). The IOLMaster can automatically measure the horizontal WTW diameter based on a digital image of the anterior segment that it acquires. The ACD and AL were also measured using an IOL Master 500. Corneal astigmatism was measured by corneal topography (Pentacam HR; Oculus Optikgeräte, Wetzlar, Germany).

2.3. Postoperative follow-up

One month after surgery, postoperative examinations were performed, which included spherical equivalent (SE) and measurements of the uncorrected distance visual acuity (UDVA), best corrected distance visual acuity (CDVA), uncorrected near visual acuity (UNVA) and distance-corrected near visual acuity (DCNVA) at 40 cm. The depth of focus was computed by adding the vergence intervals that showed continuous vision superior to 0.3 logMAR.

Pupil parameters, including pupil size, angle κ (quantified as the distance in mm between the pupillary center and the center of alignment light/fixation) and angle α (quantified as the distance in mm between the cornea center and the center of alignment light/fixation), were measured using an OPD-Scan III aberrometer (Nidek Co., Ltd., Gamagori, Japan) under photopic and mesopic conditions. Additionally, the system recorded the vector of change between the photopic and mesopic pupil centers, documenting the distance in mm and the angle of travel, serving as an MPDist. Corneal aberrations (total, HOAs, coma, trefoil, and spherical aberrations) and corneal astigmatism were measured using the same instrument. IOL tilts and IOL decentrations were also assessed using an OPD-Scan III aberrometer.

The objective optical quality, including the area ratio (AR) of the MTF and the Strehl ratio (SR) of the PSF, was evaluated with an OPD-Scan III aberrometer at both 3.0 mm and 5.0 mm pupil diameters (PDs). MTF total and SR total values were calculated from the total aberrations in one measurement, while the MTF HO and SR HO values were calculated from only HOAs that corresponded to the MTF and SR values with the correction of refractive errors.

Subjective contrast sensitivity (CS) was measured after best distance correction by the functional acuity contrast test (FACT) of the Optec 6500 view-in test system (Stereo Optical Co., Inc., Chicago, Illinois, USA) at spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per

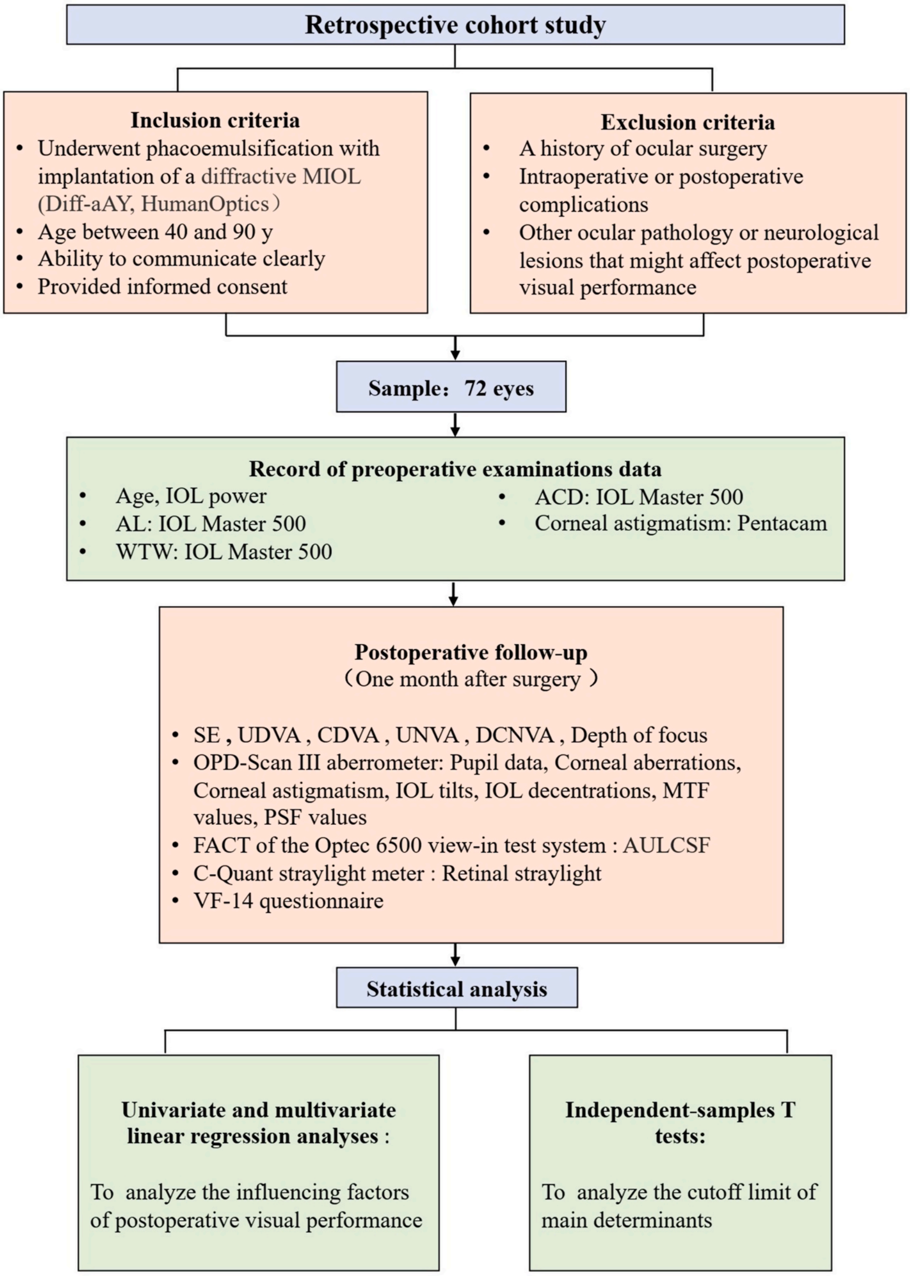

Fig. 1. A flowchart of the study process. WTW = white-to-white distance, ACD = anterior chamber depth, AL = axial length, SE = spherical equivalent, UDVA = uncorrected distance visual acuity, UNVA = uncorrected near visual acuity, CDVA = best corrected distance visual acuity, DCNVA = distance-corrected near visual acuity, MTF = modulation transfer function, PSF = point spread function, FACT = functional acuity contrast test, AULCSF = area under log contrast sensitivity function, VF-14 = Visual Function Index-14.

degree (cpd) under photopic (85 cd/square meter [cd/m^2]) and mesopic (3 cd/m^2) conditions with and without glare. Absolute values of log10 CS were obtained for each spatial frequency, and the area under the log CS function (AULCSF) was then calculated from the AULCSF curve from 1.5 to 18 cpd. Retinal straylight measurements were performed with a C-Quant straylight meter (Oculus Optikgeräte GmbH, Wetzlar, Germany).

At the end of the 1-month follow-up, a subjective questionnaire on visual perception for various activities, spectacle dependence, dysphotopsia symptoms, and overall satisfaction was administered to all participants. According to our previous study, visual perceptions were assessed with the VF-14 questionnaire [11]. The spectacle dependence for total vision activities and the subjective perception of glare and halos were analyzed by two direct 4-point Likert-type questions. Finally, the patients were asked to indicate their level of overall satisfaction using a 5-point Likert scale. In all questionnaires, higher scores indicated better visual outcomes.

2.4. Statistical analysis

All of the statistical analyses were performed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). The correlations of postoperative visual performance with biometric parameters were determined by univariate and multivariate linear regression analyses. Contributing factors with $P < 0.2$ in the univariate analysis were included in the multivariate linear regression model. Independent-samples t tests were then used to compare the visual outcomes of 2 subgroups stratified by age, cornea trefoil, IOL decentration, postoperative SE and photopic pupil size (the main determinants of postoperative visual performance identified by univariate and multivariate linear regression analyses). $P < 0.05$ was considered to indicate statistical significance.

The process for this study is shown in Fig. 1.

3. Results

3.1. Participants' clinic characteristics and postoperative visual performance

The final sample comprised 72 eyes of 72 patients (32 men and 40 women). The patients ranged in age from 41 to 86 y, with a mean age of 64.13 y ± 9.20 (SD). Table 1 shows the clinical characteristics of these patients, which were the factors potentially influencing postoperative visual performance included in this study, and Table 2 shows the postoperative visual performance parameters.

3.2. Risk factors associated with visual outcomes

Table 3 shows the univariate linear regression analysis results for all of the visual outcomes. We only listed the associated clinical parameters with p values less than 0.2, which were included in the subsequent multivariate linear regression model.

Table 1
Clinical characteristics of participants.

Parameter	Value (Mean ± SD)	Range
Preoperative parameter		
Age	64.13 ± 9.20	41, 86
WTW (mm)	11.60 ± 0.40	10.44, 12.44
ACD (mm)	3.30 ± 0.41	2.44, 4.01
AL (mm)	23.82 ± 1.36	21.52, 27.65
Corneal astigmatism (D)	0.70 ± 0.39	0.1, 1.25
IOL power (D)	20.22 ± 3.71	10.0, 26.0
Postoperative parameter		
Spherical equivalent (D)	0.02 ± 0.71	−1.5, 1.25
Photopic pupil size (mm)	3.10 ± 0.54	2.2, 4.47
Mesopic pupil size (mm)	4.54 ± 0.83	3.03, 6.87
Photopic angle κ (mm)	0.21 ± 0.10	0.02, 0.47
Mesopic angle κ (mm)	0.24 ± 0.13	0.03, 0.56
MPDist (mm)	0.11 ± 0.09	0.01, 0.45
Photopic angle α (mm)	0.46 ± 0.18	0.07, 0.70
Mesopic angle α (mm)	0.46 ± 0.20	0.07, 0.88
Corneal total aberrations	1.09 ± 0.79	0.15, 1.96
Corneal HOAs	0.40 ± 0.18	0.20, 1.36
Corneal coma	0.20 ± 0.14	0.02, 0.82
Corneal trefoil	0.23 ± 0.14	0.04, 0.85
Corneal spherical	0.14 ± 0.06	0.01, 0.31
Corneal astigmatism (D)	−0.78 ± 0.51	−1.68, −0.10
IOL tilt (mm)	0.48 ± 0.93	0.06, 1.74
IOL decentration (mm)	0.26 ± 0.20	0.05, 1.40

SD = standard deviation, WTW = white-to-white distance, ACD = anterior chamber depth, AL = axial length, IOL = intraocular lens, MPDist = pupil center shift from photopic to mesopic conditions, HOAs = high-order aberrations.

Table 2
Visual outcomes and visual function questionnaire scores of patients.

Parameter	Value (Mean ± SD)	Range
UDVA (logMAR, 5 m)	0.09 ± 0.13	−0.08, 0.52
UNVA (logMAR, 40 cm)	0.26 ± 0.16	−0.10, 0.70
CDVA (logMAR, 5 m)	0.00 ± 0.07	−0.18, 0.15
DCNVA (logMAR, 40 cm)	0.20 ± 0.12	−0.10, 0.49
Depth of focus	2.63 ± 1.05	0.50, 5.00
AR of MTF total (3 mm PD) (%)	40.75 ± 13.39	14.10, 72.40
AR of MTF HO (3 mm PD) (%)	65.07 ± 20.33	26.10, 105.50
AR of MTF total (5 mm PD) (%)	42.46 ± 12.84	13.90, 70.90
AR of MTF HO (5 mm PD) (%)	53.08 ± 16.80	13.90, 92.40
SR of PSF total (3 mm PD)	0.12 ± 0.08	0.01, 0.35
SR of PSF HO (3 mm PD)	030 ± 0.18	0.04, 0.72
SR of PSF total (5 mm PD)	0.03 ± 0.02	0.00, 0.11
SR of PSF HO (5 mm PD)	0.06 ± 0.03	0.00, 0.17
Retinal straylight (log units)	1.41 ± 0.21	0.89, 1.87
Retinal straylight (Esd)	0.06 ± 0.01	0.05, 0.08
AULCSF (photopic conditions without glare)	22.97 ± 3.80	10.7, 30.72
AULCSF (photopic conditions with glare)	22.02 ± 4.22	10.07, 30.72
AULCSF (mesopic conditions without glare)	18.72 ± 5.08	4.99, 32.84
AULCSF (mesopic conditions with glare)	14.56 ± 6.12	0.63, 30.36
Total VF-14 score	90.70 ± 7.68	66.85, 100
Spectacle dependence (distance)	3.99 ± 0.12	3.00, 4.00
Spectacle dependence (near)	3.49 ± 0.80	1.00, 4.00
Glare	3.22 ± 1.00	1.00, 4.00
Halos	3.25 ± 0.99	1.00, 4.00
Satisfaction score	3.88 ± 0.77	2.00, 5.00

SD = standard deviation, UDVA = uncorrected distance visual acuity, UNVA = uncorrected near visual acuity, CDVA = best corrected distance visual acuity, DCNVA = distance-corrected near visual acuity, logMAR = logarithm of the minimum angle of resolution. AR = area ratio, MTF = modulation transfer function, SR=Strehl ratio, PSF = point spread function, Total: indicates data calculated from total aberration, HO: indicates data calculated from only high order aberration, PD = pupil diameter, Esd = standard deviation of the individual measuring point as defined by the straylight meter, AULCSF = area under log contrast sensitivity function, VF-14 = Visual Function Index-14.

1) Risk factors associated with visual acuity

Through further multivariate linear regression analyses, we discovered that IOL decentration was the only independent risk factor for a clinically significant decrease in DCNVA (beta = 0.314, P = 0.007; Table S1). As shown in Table S1, the prediction model for IOL decentration on DCNVA performed well, and for each mm increase in IOL decentration, DCNVA decreased by 0.314 logMAR (P = 0.016, adj. $R^2 = 0.136$).

Multivariate regression was then performed to predict the CDVA (Table S2). Only IOL power (beta = −0.377, P = 0.005) was a statistically significant risk factor for CDVA (P = 0.001, adj. $R^2 = 0.244$). Every 1 D increase in IOL power improved the CDVA by 0.377 logMAR.

Additionally, we conducted multivariate linear regression for the depth of focus, and we did not obtain a statistically significant prediction model (data not shown).

2) Risk factors associated with the AR of the MTF

The only significant negative correlation was found between age (beta = −0.288, P = 0.019) and the total AR of the MTF (3 mm PD) (P = 0.015, adj. $R^2 = 0.155$, Table S3) after multivariate linear regression analysis. Additionally, age (beta = −0.353, P = 0.010) was the only statistically significant risk factor for the AR of MTF HO (3 mm PD) ($P < 0.001$, adj. $R^2 = 0.312$ Table S4). According to the multivariate analysis for the total AR of the MTF (5 mm PD), preoperative corneal astigmatism (beta = −0.261, P = 0.020) and SE (beta = 0.261, P = 0.017) were significantly associated with the AR of the MTF ($P < 0.001$, adj. $R^2 = 0.264$, Table S5). As illustrated in Table S6, a model comprising age (beta = −0.222, P = 0.035) and corneal trefoil (beta = −0.330, P = 0.036) predicted the AR of MTF HO (5 mm PD) ($p < 0.001$, adj. $R^2 = 0.374$).

3) Risk factors associated with the SR of the PSF

The results of the univariate analyses of regression models for the SR of the PSF are displayed in Table 3. Multivariate regression analysis was then performed to determine the associations between the SR of PSF total (3 mm PD) and the associated factors. The SR of PSF total (3 mm PD) depended only on age (beta = −0.269, P = 0.031) (p = 0.037, adj. $R^2 = 0.114$) (Table S7). The younger the patient was, the better the postoperative SR of PSF total (3 mm PD). Our multiple regression analysis also revealed that age (beta = −0.285, P = 0.038) and corneal trefoil (beta = −0.335, P = 0.027) were negatively associated with the SR of PSF HO (3 mm PD) ($P < 0.001$, adj.

Table 3
Univariate analyses of the associations between the visual outcomes and the clinical parameters (P < 0.2).

Parameter	Beta	P
DCNVA		
Age	0.339	0.004[a]
AL	0.217	0.068
IOL power	−0.248	0.036[a]
Corneal HOAs	0.161	0.176
Corneal trefoil	0.154	0.196
IOL decentration	0.389	0.001[a]
CDVA		
Age	0.400	<0.001[a]
ACD	−0.267	0.023[a]
IOL power	−0.184	0.121
Corneal HOAs	0.313	0.007[a]
Corneal coma	0.313	0.091
Corneal trefoil	0.260	0.027[a]
Postoperative Corneal astigmatism	0.168	0.158
Depth of focus		
AL	−0.158	0.186
IOL power	0.191	0.108
Photopic pupil size	−0.430	<0.001[a]
Mesopic pupil size	−0.314	0.007[a]
Photopic angle α	0.159	0.181
Mesopic angle α	0.306	0.009[a]
Corneal total aberrations	0.165	0.165
Corneal spherical	0.234	0.048[a]
Postoperative Corneal astigmatism	−0.202	0.089
IOL decentration	−0.202	0.089
AR of MTF total (3 mm PD) (%)		
Age	−0.379	0.001[a]
AL	−0.196	0.099
Preoperative corneal astigmatism	−0.203	0.086
IOL power	0.162	0.175
Spherical equivalent	0.298	0.011[a]
Mesopic angle κ	0.175	0.141
Corneal HOAs	−0.248	0.036[a]
Corneal coma	−0.177	0.136
AR of MTF HO (3 mm PD) (%)		
Age	−0.472	<0.001
WTW	0.209	0.078
ACD	0.273	0.020[a]
AL	−0.172	0.149
IOL power	0.164	0.170
Spherical equivalent	0.271	0.021[a]
Corneal HOAs	−0.304	0.009[a]
Corneal trefoil	−0.366	0.002[a]
Postoperative Corneal astigmatism	−0.185	0.119
AR of MTF total (5 mm PD) (%)		
Age	−0.416	<0.001[a]
AL	−0.288	0.014[a]
Preoperative corneal astigmatism	−0.292	0.013[a]
IOL power	0.213	0.073
Spherical equivalent	0.340	0.003[a]
Corneal HOAs	−0.301	0.010[a]
Corneal trefoil	−0.340	0.003[a]
AR of MTF HO (5 mm PD) (%)		
Age	−0.293	0.013[a]
AL	−0.228	0.054
Preoperative corneal astigmatism	−0.159	0.183
IOL power	0.166	0.163
Spherical equivalent	0.318	0.006[a]
Photopic angle α	−0.188	0.114
Corneal HOAs	−0.451	<0.001[a]
Corneal trefoil	−0.559	<0.001[a]
IOL tilt	0.154	0.199
SR of PSF total (3 mm PD)		
Age	−0.352	0.002[a]
AL	−0.221	0.062
Preoperative corneal astigmatism	−0.229	0.053

(*continued on next page*)

Table 3 (*continued*)

Parameter	Beta	P
IOL power	0.181	0.129
Spherical equivalent	0.256	0.030[a]
Mesopic angle κ	0.189	0.112
Cornea HOAs	−0.195	0.101
SR of PSF HO (3 mm PD)		
Age	−0.472	<0.001[a]
WTW	0.197	0.097
ACD	0.296	0.012[a]
AL	−0.167	0.160
Spherical equivalent	0.259	0.028[a]
Mesopic angle α	−0.167	0.161
Cornea HOAs	−0.301	0.010[a]
Cornea trefoil	−0.378	0.001[a]
Postoperative Corneal astigmatism	−0.198	0.095
SR of PSF total (5 mm PD)		
Age	−0.393	0.001[a]
AL	−0.307	0.009[a]
Preoperative corneal astigmatism	−0.244	0.039[a]
IOL power	0.261	0.027[a]
Spherical equivalent.	0.275	0.020[a]
Mesopic angle κ	0.174	0.144
Cornea HOAs	−0.222	0.061
Cornea trefoil	−0.255	0.030[a]
IOL tilt	0.158	0.189
SR of PSF HO (5 mm PD)		
Age	−0.293	0.013*
AL	−0.228	0.054
Preoperative corneal astigmatism	−0.159	0.183
IOL power	0.166	0.163
Spherical equivalent	0.318	0.006[a]
Photopic angle α	−0.188	0.114
Cornea HOAs	−0.451	<0.001[a]
Cornea trefoil	−0.559	<0.001[a]
IOL tilt	0.154	0.199
AULCSF (photopic conditions without glare)		
Age	−0.397	0.001[a]
ACD	0.254	0.031[a]
AL	−0.193	0.104
IOL power	0.229	0.053
Photopic pupil size	−0.248	0.036
Photopic angle κ	0.159	0.183
Postoperative Corneal astigmatism	−0.301	0.010[a]
IOL decentration	−0.195	0.100
AULCSF (photopic conditions with glare)		
Age	−0.368	0.001[a]
WTW	0.180	0.130
ACD	0.189	0.111
IOL power	0.224	0.058
Cornea spherical	0.189	0.112
Postoperative Corneal astigmatism	−0.241	0.042
IOL tilt	−0.157	0.192
IOL decentration	−0.233	0.049[a]
AULCSF (mesopic conditions without glare)		
Age	−0.279	0.018[a]
ACD	0.176	0.140
AL	−0.212	0.074
IOL power	0.273	0.020
Photopic pupil size	−0.208	0.079
Postoperative Corneal astigmatism	0.191	0.108
AULCSF (mesopic conditions with glare)		
Age	−0.316	0.007[a]
ACD	0.218	0.065
AL	−0.199	0.093
IOL power	0.258	0.029[a]
Photopic pupil size	−0.169	0.155
Cornea HOAs	−0.190	0.110
Postoperative Corneal astigmatism	−0.354	0.002
IOL decentration	−0.190	0.109
Retinal straylight (log units)		

(*continued on next page*)

Table 3 (*continued*)

Parameter	Beta	P
Age	0.387	0.001[a]
ACD	−0.168	0.159
Photopic angle κ	−0.159	0.183
Corneal HOAs	0.243	0.040[a]
Corneal trefoil	0.297	0.011
Postoperative Corneal astigmatism	0.169	0.155
IOL decentration	0.206	0.082
Glare		
Mesopic pupil size	−0.157	0.187
Corneal total aberrations	0.215	0.070
Corneal trefoil	−0.157	0.187
Halos		
Spherical equivalent	0.205	0.083
Photopic angle κ	0.207	0.080
Mesopic angle κ	0.258	0.029[a]
Corneal total aberrations	0.299	0.011[a]
Corneal HOAs	0.178	0.136
Postoperative Corneal astigmatism	−0.205	0.084
IOL tilt	0.165	0.169
Total VF-14 score		
AL	−0.223	0.059
IOL power	0.245	0.038
Spherical equivalent	−0.293	0.013[a]
Photopic pupil size	−0.311	0.008[a]
Mesopic pupil size	−0.154	0.196
MPDist	0.189	0.112
Corneal total aberrations	0.221	0.062
IOL decentration	−0.249	0.035[a]
Spectacle dependence (distance)		
ACD	0.171	0.150
AL	0.191	0.107
IOL power	−0.192	0.107
Corneal spherical	−0.175	0.143
Postoperative Corneal astigmatism	0.186	0.118
Spectacle dependence (near)		
Age	−0.236	0.046[a]
Spherical equivalent	−0.161	0.178
Photopic angle α	0.154	0.198
Postoperative Corneal astigmatism	−0.170	0.153
IOL decentration	−0.161	0.178
Satisfaction score		
IOL power	0.198	0.096
Spherical equivalent	−0.456	<0.001[a]
Photopic pupil size	−0.307	0.009[a]
Photopic angle α	0.219	0.064
Corneal total aberrations	0.215	0.070
Postoperative Corneal astigmatism	−0.164	0.168
IOL decentration	−0.256	0.030[a]

CDVA = best corrected distance visual acuity, DCNVA = distance-corrected near visual acuity, WTW = white-to-white distance, ACD = anterior chamber depth, AL = axial length, IOL = intraocular lens, MPDist = pupil center shift from photopic to mesopic conditions, AR = area ratio, MTF = modulation transfer function, SR=Strehl ratio, PSF = point spread function, Total: indicates data calculated from total aberration, HO: indicates data calculated from only high order aberration, PD = pupil diameter, HOAs = high-order aberrations, AULCSF = area under log contrast sensitivity function, VF-14 = Visual Function Index-14.

[a] Statistically significant ($P < 0.05$).

$R^2 = 0.291$, Table S8). Furthermore, we found that only corneal trefoil (beta = −0.382, P = 0.023) was an independent influencing factor for SR of PSF HO (5 mm PD) ($P < 0.001$, adj. $R^2 = 0.287$, Table S9). No significant correlations between the SR of PSF total (5 mm PD) and any of the biometric parameters measured were found (data not shown).

4) Risk factors associated with the AULCSF

According to the multivariate analysis for AULCSF (photopic conditions without glare), the AULCSF was negatively associated with age (beta = −0.396, P = 0.005) and photopic pupil size (beta = −0.422, P = 0.001) (P = 0.001, adj. $R^2 = 0.256$) (Table S10). According to the multivariate analysis of the AULCSF under photopic conditions with glare, a larger WTW (beta = 0.279, P = 0.022) and less IOL decentration (beta = −0.250, P = 0.035) were more likely to result in a better AULCSF (p = 0.014, adj. $R^2 = 0.159$) (Table S11). According to the multivariate analysis of the AULCSF under mesopic conditions without glare, only the photopic pupil size (beta =

Table 4
Comparison of visual outcomes and visual function questionnaire scores between the 2 subgroups stratified by main determinants.

Parameter (Mean ± SD)	Below the cutoff limit	Above the cutoff limit	P value
Age (<65: 40 0eyes; ≥65: 32 eyes)			
CDVA (5 m)	−0.02 ± 0.07	0.02 ± 0.06	0.006[a]
DCNVA (40 cm)	0.18 ± 0.11	0.24 ± 0.12	0.043[a]
Depth of focus	2.75 ± 1.06	2.48 ± 1.03	0.288
AR of MTF total (3 mm PD) (%)	44.98 ± 13.34	35.47 ± 11.63	0.002[a]
AR of MTF HO (3 mm PD) (%)	72.31 ± 17.79	56.02 ± 19.92	<0.001[a]
AR of MTF total (5 mm PD) (%)	46.64 ± 12.59	37.23 ± 11.30	0.002[a]
AR of MTF HO (5 mm PD) (%)	57.91 ± 15.30	47.05 ± 16.87	0.006[a]
SR of PSF total (3 mm PD)	0.15 ± 0.08	0.09 ± 0.06	0.004[a]
SR of PSF HO (3 mm PD)	0.36 ± 0.17	0.23 ± 0.16	0.002[a]
SR of PSF total (5 mm PD)	0.04 ± 0.02	0.03 ± 0.02	0.010[a]
SR of PSF HO (5 mm PD)	0.06 ± 0.03	0.05 ± 0.03	0.044[a]
Retinal straylight (log units)	1.34 ± 0.20	1.49 ± 0.20	0.003[a]
AULCSF (photopic conditions without glare)	23.97 ± 3.97	21.71 ± 3.21	0.011[a]
AULCSF (photopic conditions with glare)	23.05 ± 4.03	20.73 ± 4.14	0.019[a]
AULCSF (mesopic conditions without glare)	19.95 ± 5.01	17.19 ± 4.82	0.021[a]
AULCSF (mesopic conditions with glare)	16.20 ± 5.60	12.52 ± 6.21	0.010[a]
Total VF-14 score	91.26 ± 7.37	90.00 ± 8.11	0.490
Spectacle dependence (distance)	3.98 ± 0.16	4.00 ± 0.00	0.375
Spectacle dependence (near)	3.63 ± 0.74	3.31 ± 0.86	0.102
Glare	3.10 ± 1.06	3.38 ± 0.91	0.247
Halos	3.20 ± 1.04	3.21 ± 0.93	0.635
Satisfaction score	3.95 ± 0.75	3.78 ± 0.79	0.358
Cornea trefoil (≤0.20 mm: 35 eyes; >0.20 mm: 37 eyes)			
CDVA (5 m)	−0.02 ± 0.06	0.01 ± 0.07	0.045[a]
DCNVA (40 cm)	0.19 ± 0.13	0.22 ± 0.11	0.335
Depth of focus	2.63 ± 1.05	2.64 ± 1.06	0.979
AR of MT total (3 mm PD) (%)	41.77 ± 15.39	39.78 ± 11.33	0.537
AR of MTF HO (3 mm PD) (%)	72.45 ± 20.35	58.09 ± 17.92	0.002[a]
AR of MTF total (5 mm PD) (%)	45.04 ± 14.83	40.01 ± 10.25	0.101
AR of MTF HO (5 mm PD) (%)	59.75 ± 16.51	46.77 ± 14.68	0.001[a]
SR of PSF total (3 mm PD)	0.13 ± 0.09	0.12 ± 0.06	0.469
SR of PSF HO (3 mm PD)	0.37 ± 0.19	0.24 ± 0.14	0.001[a]
SR of PSF total (5 mm PD)	0.04 ± 0.03	0.03 ± 0.02	0.076
SR of PSF HO (5 mm PD)	0.07 ± 0.04	0.04 ± 0.03	<0.001[a]
Retinal straylight (log units)	1.34 ± 0.20	1.47 ± 0.21	0.007[a]
AULCSF (photopic conditions without glare)	23.88 ± 3.01	22.11 ± 4.29	0.047[a]
AULCSF (photopic conditions with glare)	23.08 ± 3.52	21.02 ± 4.61	0.037[a]
AULCSF (mesopic conditions without glare)	19.81 ± 5.05	17.69 ± 4.96	0.077
AULCSF (mesopic conditions with glare)	16.13 ± 5.73	13.08 ± 6.18	0.034[a]
Total VF-14 score	91.07 ± 8.10	90.36 ± 7.35	0.699
Spectacle dependence (distance)	3.97 ± 0.17	4.00 ± 0.00	0.324
Spectacle dependence (near)	3.54 ± 0.82	3.43 ± 0.80	0.564
Glare	3.31 ± 0.90	3.14 ± 1.08	0.450
Halos	3.09 ± 1.09	3.41 ± 0.86	0.172
Satisfaction score	3.89 ± 0.72	3.86 ± 0.82	0.909
Photopic pupil size (<3.0 mm: 34 eyes; ≥3.0 mm: 38 eyes)			
CDVA (5 m)	−0.01 ± 0.05	0.01 ± 0.08	0.192
DCNVA (40 cm)	0.19 ± 0.12	0.22 ± 0.12	0.335
Depth of focus	3.07 ± 0.90	2.24 ± 1.02	<0.001[a]
Retinal straylight (log units)	1.44 ± 0.17	1.38 ± 0.25	0.255
AULCSF (photopic conditions without glare)	24.04 ± 3.40	22.01 ± 3.93	0.022[a]
AULCSF (photopic conditions with glare)	23.16 ± 3.78	21.00 ± 4.37	0.029[a]
AULCSF (mesopic conditions without glare)	19.89 ± 4.51	17.68 ± 5.39	0.064
AULCSF (mesopic conditions with glare)	15.62 ± 5.87	13.61 ± 6.25	0.165
Total VF-14 score	92.30 ± 7.12	89.27 ± 7.97	0.095
Spectacle dependence (distance)	3.97 ± 0.17	4.00 ± 0.00	0.325
Spectacle dependence (near)	3.35 ± 0.92	3.61 ± 0.68	0.186
Glare	3.35 ± 0.85	3.11 ± 1.11	0.295
Halos	3.38 ± 0.92	3.13 ± 1.04	0.286
Satisfaction score	4.06 ± 0.85	3.71 ± 0.65	0.054
IOL decentration (<0.30 mm: 50 eyes, ≥0.30 mm: 2 eyes)			
CDVA (5 m)	−0.01 ± 0.07	0.02 ± 0.06	0.058
DCNVA (40 cm)	0.18 ± 0.12	0.26 ± 0.11	0.011[a]
Depth of focus	2.81 ± 1.05	2.23 ± 0.94	0.029[a]
AR of MTF total (3 mm PD) (%)	40.93 ± 13.60	40.33 ± 13.22	0.862
AR of MTF HO (3 mm PD) (%)	67.81 ± 19.19	58.83 ± 21.91	0.084
AR of MTF total (5 mm PD) (%)	42.11 ± 13.32	43.24 ± 11.96	0.733

(continued on next page)

Table 4 (*continued*)

Parameter (Mean ± SD)	Below the cutoff limit	Above the cutoff limit	P value
AR of MTF HO (5 mm PD) (%)	54.33 ± 16.24	50.24 ± 18.09	0.345
SR of PSF total (3 mm PD)	0.12 ± 0.07	0.12 ± 0.08	0.883
SR of PSF HO (3 mm PD)	0.32 ± 0.18	0.26 ± 0.18	0.158
SR of PSF total (5 mm PD)	0.03 ± 0.02	0.03 ± 0.02	0.952
SR of PSF HO (5 mm PD)	0.06 ± 0.03	0.05 ± 0.03	0.658
Retinal straylight (log units)	1.36 ± 0.21	1.51 ± 0.20	0.006[a]
AULCSF (photopic conditions without glare)	23.66 ± 3.99	21.39 ± 2.84	0.018[a]
AULCSF (photopic conditions with glare)	22.93 ± 4.09	19.94 ± 3.81	0.005[a]
AULCSF (mesopic conditions without glare)	19.40 ± 5.32	17.19 ± 4.22	0.090
AULCSF (mesopic conditions with glare)	15.95 ± 6.00	11.40 ± 5.25	0.003[a]
Total VF-14 score	92.07 ± 7.00	87.59 ± 8.40	0.021[a]
Spectacle dependence (distance)	3.98 ±0.14	4.00 ± 0.00	0.511
Spectacle dependence (near)	3.58 ± 0.73	3.27 ± 0.94	0.137
Glare	3.20 ± 1.07	3.27 ± 0.83	0.755
Halos	3.26 ± 0.99	3.23 ± 1.02	0.898
Satisfaction score	4.00 ± 0.73	3.59 ± 0.80	0.036[a]
SE (≤0.00 D: 35 eyes; >0.00 D: 37 eyes)			
CDVA (5 m)	0.00 ± 0.08	0.00 ± 0.06	0.820
DCNVA (40 cm)	0.22 ± 0.15	0.19 ± 0.09	0.354
Depth of focus	2.87 ± 1.10	2.41 ± 0.95	0.059
AR of MTF (3 mm PD) (%)	35.35 ± 11.51	45.86 ± 13.17	0.001[a]
AR of MTF HO (3 mm PD) (%)	59.28 ± 20.12	70.54 ± 19.23	0.018[a]
AR of MTF (5 mm PD) (%)	37.62 ± 12.65	47.03 ± 11.41	0.001[a]
AR of MTF HO (5 mm PD) (%)	46.87 ± 16.28	58.96 ± 15.29	0.002[a]
SR of PSF (3 mm PD)	0.10 ± 0.06	0.15 ± 0.08	0.002[a]
SR of PSF HO (3 mm PD)	0.26 ± 0.17	0.34 ± 0.17	0.034[a]
SR of PSF (5 mm PD)	0.03 ± 0.02	0.04 ± 0.02	0.018[a]
SR of PSF HO (5 mm PD)	0.04 ± 0.03	0.07 ± 0.04	0.009[a]
Retinal straylight (log units)	1.40 ± 0.20	1.41 ± 0.23	0.883
AULCSF (photopic conditions without glare)	23.51 ± 4.09	22.45 ± 3.49	0.240
AULCSF (photopic conditions with glare)	22.40 ± 4.86	21.65 ± 3.53	0.459
AULCSF (mesopic conditions without glare)	18.60 ± 5.83	18.84 ± 4.34	0.846
AULCSF (mesopic conditions with glare)	14.79 ± 6.57	14.35 ± 5.74	0.765
Total VF-14 score	91.93 ± 7.62	89.54 ± 7.65	0.187
Spectacle dependence (distance)	3.97 ± 0.17	4.00 ± 0.00	0.324
Spectacle dependence (near)	3.60 ± 0.65	3.38 ± 0.92	0.246
Glare	3.03 ± 1.01	3.41 ± 0.96	0.109
Halos	3.09 ± 0.92	3.41 ± 1.04	0.172
Satisfaction score	4.20 ± 0.63	3.57 ± 0.77	<0.001[a]

CDVA = best corrected distance visual acuity, DCNVA = distance-corrected near visual acuity, AR = area ratio, MTF = modulation transfer function, SR=Strehl ratio, PSF = point spread function, Total: indicates data calculated from total aberration, HO: indicates data calculated from only high order aberration, PD = pupil diameter, AULCSF = area under log contrast sensitivity function, VF-14 = Visual Function Index-14, IOL = intraocular lens, SE = spherical equivalent.

[a] Statistically significant ($P < 0.05$).

−0.262, P = 0.029) was significantly correlated (p = 0.002, adj. R^2 = 0.205) (Table S12). A smaller photopic pupil size was significantly associated with a greater AULCSF in mesopic conditions without glare. In the multivariate analysis for the AULCSF under mesopic conditions with glare, we obtained a model comprising the ACD (beta = 0.269, P = 0.035), corneal HOAs (beta = −0.281, P = 0.023) and postoperative corneal astigmatism (beta = −0.348, P = 0.006) that predicted the AULCSF (P < 0.001, adj. R^2 = 0.310) (Table S13).

5) Risk factors associated with dysphotopsia phenomena

After multivariable regression analyses, we demonstrated that both age (beta = 0.266, P = 0.033) and IOL decentration (beta = 0.281, P = 0.013) had a significant positive influence on retinal straylight (P = 0.001, adj. R^2 = 0.228, Table S14). However, no significant predictors of glare or halo perception were obtained (data not shown).

6) Risk factors associated with visual function questionnaire scores

Further multivariable regression analyses indicated that SE (beta = −0.257, P = 0.043) was a significant determinant of the VF-14 score (p = 0.006, adj. R^2 = 0.188, Table S15). Additionally, SE (beta = −0.378, P = 0.002) was the only significant influencing factor for the satisfaction score (P = 0.001, adj. R^2 = 0.238, Table S16). For the spectacle dependence score, we did not obtain a statistically significant prediction model (data not shown).

3.3. Subgroup analyses of visual performance stratified by main determinants

To help clinicians make optimal treatment decisions, we further compared the visual performance between the subgroups stratified by the main determinants (identified by univariate and multivariate linear regression analyses). We selected age, corneal trefoil, photopic pupil size, IOL decentration and SE as the main determinants, all of which were significantly associated with at least two postoperative visual performance parameters.

First, we compared the visual outcomes between the 2 subgroups stratified by age (<65 y or ≥65 y). Table 4 shows that the younger subgroup (<65 y, 40 eyes) had significantly better CDVA ($P = 0.006$) and DCNVA ($P = 0.043$) than did the older subgroup (≥65 y, 32 eyes). In patients <65 y, the MTF and PSF values were significantly greater than those in patients ≥65 y ($P < 0.05$). Additionally, the AULCSF values in any lighting condition with or without glare and retinal straylight were significantly worse for patients aged ≥65 y ($P < 0.05$).

Subgroup analyses of different corneal trefoil groups were also performed. CDVA was significantly better in the small corneal trefoil subgroup (≤0.20 mm, 35 eyes) than in the large corneal trefoil subgroup (>0.20 mm, 37 eyes) ($P = 0.045$, Table 4). The MTF HO and PSF HO at both 3.0 mm and 5.0 mm PD were significantly higher in the small corneal trefoil subgroup than in the large corneal trefoil subgroup ($P < 0.01$). Regarding retinal straylight, the small corneal trefoil subgroup presented significantly better results than did the large corneal trefoil subgroup ($P = 0.007$). In addition, a significantly greater AULCSF was obtained in the small corneal trefoil subgroup than in the large corneal trefoil subgroup under photopic conditions with and without glare and under mesopic conditions with glare ($P < 0.05$).

We then divided the patients into two photopic pupil size subgroups. Notably, among patients with a photopic pupil size <3.0 mm (34 eyes), a significantly greater depth of focus was observed than in the large photopic pupil size subgroup (≥3.0 mm, 38 eyes) ($P < 0.001$, Table 4). AULCSF was significantly greater in the small photopic pupil size subgroup than in the large photopic pupil size subgroup under photopic conditions with and without glare ($P < 0.05$, Table 4).

According to subgroup analyses stratified by IOL decentration, patients with IOL decentration <0.30 mm (50 eyes) had significantly better DCNVA and depth of focus than patients in the large IOL decentration subgroup (≥0.30 mm, 22 eyes) ($P < 0.05$, Table 4). Similarly, retinal straylight was significantly better in the small IOL decentration subgroup ($P = 0.006$, Table 4). A higher AULCSF was also obtained in the small-IOL decentration subgroup than in the large-IOL decentration subgroup under photopic conditions with and without glare and under mesopic conditions with glare ($P < 0.05$, Table 4). Additionally, significantly better VF-14 and satisfaction scores were reported in the small-IOL decentration subgroup than in the large-IOL decentration subgroup ($P < 0.05$, Table 4).

We also performed subgroup analyses based on different postoperative SEs and found that the MTF and PSF values were significantly better in the positive SE subgroup (>0.00 D, 37 eyes) than in the negative SE subgroup (≤0.00 D, 35 eyes) ($P < 0.05$, Table 4). However, the depth of focus was greater in the negative SE subgroup than in the positive SE subgroup, although the difference was not statistically significant ($P = 0.059$, Table 4). Patients with negative SEs were significantly more satisfied with the postoperative

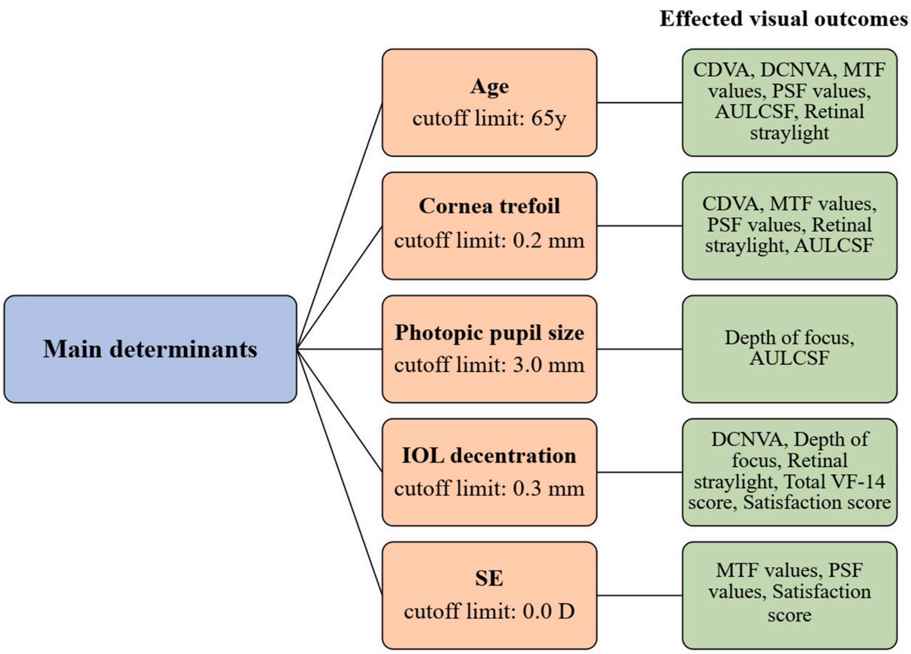

Fig. 2. Cutoff limits of the main determinants of postoperative visual outcomes. CDVA = best corrected distance visual acuity, DCNVA = distance-corrected near visual acuity, MTF = modulation transfer function, PSF = point spread function, AULCSF = area under log contrast sensitivity function, VF-14 = Visual Function Index-14.

outcomes ($p < 0.001$, Table 4).

Finally, we summarized the cutoff limits of the main determinants (age, corneal trefoil, photopic pupil size, IOL decentration and SE) of postoperative visual outcomes, as shown in Fig. 2. Clinical outcomes can be altered significantly when these indicators are below or above this threshold.

4. Discussion

The putatively uniform desire for spectacle-free vision following cataract surgery has paved the way for the development of MIOLs. The cost of MIOLs is generally high, and patients often have high expectations for postoperative visual results. Therefore, the identification of clinical parameters that are predictive of future surgical outcomes is of vital importance, as such information will be essential to aid individual patients in choosing the most personally beneficial cataract surgery option.

In the present study, we considered a more comprehensive set of postoperative visual quality parameters and their potential influencing factors than did previous investigations. Consequently, we obtained 16 statistically significant multivariate linear regression models that predicted postoperative visual performance and demonstrated that IOL decentration, IOL power, age, corneal astigmatism, SE, photopic pupil size, corneal trefoil, WTW, ACD and corneal HOAs were significantly associated with postoperative visual performance. Additionally, we obtained the cutoff limits of the five main determinants (age, corneal trefoil, photopic pupil size, IOL decentration and SE) of postoperative visual outcomes. Clinical outcomes can be altered significantly when these indicators are below or above this threshold, which is highly important for clinical applications.

First, through univariate and multivariate linear regression analysis, we demonstrated that age was a vital determinant of postoperative visual performance after MIOL implantation. Age was significantly associated with the AR of MTF total (3 mm PD), AR of MTF HO (3 mm PD), AR of MTF HO (5 mm PD), SR of PSF total (3 mm PD), SR of PSF HO (3 mm PD), AULCSF (photopic conditions without glare) and retinal straylight. These correlations have never been reported in previous studies. Only one cross-sectional study of patients with high myopia reported that age may help predict postoperative visual quality after advanced surface ablation [12].

To initially determine the age limit for satisfying visual performance, the differences in visual performance parameters among individuals of various ages were further analyzed. The results showed that patients aged under 65 y had a significantly better mean CDVA (-0.02 ± 0.07 logMAR) than patients aged 65 y or older (0.02 ± 0.06 logMAR). DCNVA was also significantly better in the younger subgroup (0.18 ± 0.11 logMAR) than in the older subgroup (0.24 ± 0.12 logMAR). Additionally, the visual quality parameters, including the MTF and PSF values and the AULCSF in any lighting condition with or without glare and retinal straylight, were significantly better for patients aged $<$65 y. Similar to our results, Philipp et al. demonstrated that younger patients (46 ± 6 y) were more satisfied with the results of MIOL implantation than older patients (71 ± 7 y), owing to better visual acuity and contrast sensitivity [13]. However, to our knowledge, these authors did not evaluate the specific cutoff age for better postoperative visual results [13], which was explored in the present study for the first time. These age-related differences may be attributed to better retinal function in younger patients [14].

In addition, we identified corneal trefoil as a significant factor that correlated with the AR of MTF HO (5 mm PD), SR of PSF HO (3 mm PD) and SR of PSF HO (5 mm PD). A smaller corneal trefoil predicted better optical quality. Further subgroup analyses stratified by corneal trefoil suggested that a corneal trefoil of more than 0.20 mm would result in worse mean CDVA and vision quality, including MTF HO and PSF HO values at both 3.0 mm and 5.0 mm PD, retinal straylight, AULCSF under photopic conditions with or without glare, and AULCSF under mesopic conditions with glare, compared with the small corneal trefoil subgroup. There have been few reports concerning the influence of corneal trefoil on visual performance with MIOLs; previous studies focused more on corneal HOAs and demonstrated that corneal HOAs were significantly correlated with postoperative visual outcomes [6]. Consistent with these previous findings, we demonstrated a negative correlation between corneal HOAs and AULCSF under mesopic conditions with glare ($P = 0.023$).

We also found that photopic pupil size could significantly predict the AULCSF without glare. A smaller pupil size was positively correlated with greater contrast sensitivity. We set the cutoff value of photopic pupil size to 3.0 mm and found that patients with a photopic pupil size less than 3.0 mm tended to experience an increase in the depth of focus and AULCSF under photopic conditions. Similarly, Petermeier et al. reported that the depth of focus at a 3 mm pupil size was slightly broader than that at a 5 mm pupil size, although the difference was not statistically significant [15]. A small pupil size may have an additional pinhole effect, resulting in a greater depth of focus and better contrast sensitivity. Previous studies were more interested in the effect of pupil size, especially mesopic pupil size, on dysphotopsia phenomena. Javier et al. reported that patients with large pupils had more dysphotopic phenomena [16,17]. However, although the current study showed that the Likert scale scores (including both glare and halo) were better in the smaller pupil size subgroup, the difference was not statistically significant (Table 4). This is probably explained to a certain extent by differences in the selected IOLs and insufficient sample sizes.

In the current study, we used the HumanOptics diffractive MIOL. Patients implanted with this MIOL device reported low photic visual symptoms, which may be due to the optical surface design of this IOL [18]. There is a smooth transition from the diffractive zone to the outer refractive zone as the pupil enlarges. Thus, no statistically significant differences in the Likert scale scores (including both glare and halo scores) were detected between the two pupil size subgroups.

Not surprisingly, in the present study, IOL decentration was shown to have a significant influence on DCNVA, AULCSF under photopic conditions with glare, and retinal straylight according to the univariate and multivariate linear regression analyses. We then stratified the patients by IOL decentration and discovered that patients with IOL decentration $<$0.30 mm had significantly better DCNVA and depth of focus than patients in the large IOL decentration subgroup ($\geq$0.30 mm). Retinal straylight, AULCSF under photopic conditions with or without glare, and AULCSF under mesopic conditions with glare were also significantly better in the small

IOL decentration subgroup. Additionally, patients with IOL decentration <0.30 mm reported significantly higher VF-14 scores and satisfaction scores. Consistent with our findings, Mitsutaka et al. indicated that the near MTF of diffractive MIOL decreased with increasing IOL decentration [19]. Pablo et al. reported that IOL decentration resulted in decreased retinal image quality [9,20]. When IOL decentration is induced, the diffraction ring near the center (the area for near vision) cannot be fully utilized. Therefore, we assumed that near vision was easily affected by IOL decentration. In addition, we thought that one factor causing the deterioration of retinal image quality after IOL decentration may have been an increase in aberrations due to increased peripheral vision of the optical portion.

Recent studies highlight the importance of considering angle κ and angle α in MIOL implantation [5,6,21]. However, no significant correlation was found between angle α or angle κ and visual performance in our current study. A possible explanation is that both angle α and angle κ were significantly associated with IOL decentration, which was demonstrated in our previous study [22]. After adjusting for confounders through multiple regression analysis, angle α and angle κ, which were significant determinants of postoperative visual performance according to the univariate analyses ($P < 0.05$, Table 3), were excluded from the final prediction model.

SE was demonstrated to be positively correlated with the AR of MTF total (5 mm PD) and negatively correlated with VF-14 scores and satisfaction scores. Moreover, further subgroup analyses stratified by SE showed that within a certain range, patients with a less negative SE were more likely to achieve better MTF and PSF values, while patients with a more negative SE reported higher satisfaction scores. We attributed these higher satisfaction scores to the greater depth of focus in the more negative SE subgroup, although the difference was not statistically significant ($P = 0.059$, Table 4). According to these findings, we speculated that patient satisfaction after cataract surgery may depend more on the depth of focus than on visual quality to some extent. Our results corroborated the findings of Sawusch et al., who showed that the optimal depth of focus was obtained when the plus cylindrical component equaled a negative sphere of 0.25 diopters [23]. However, few previous data from the literature could be found to help understand these exact correlations. Further exploration of the etiology of these relationships is needed.

Astigmatism management is vital to the performance of MIOLs [7]. A rule of thumb is that MIOLs perform best with less than three-quarters of a diopter of a cylinder [7,24]. Consistent with these findings, our current study revealed that preoperative corneal astigmatism was negatively associated with the AR of MTF total (5 mm PD) and that lower postoperative corneal astigmatism predicted higher AULCSF under mesopic conditions with glare.

Furthermore, we identified positive correlations between WTW and AULCSF under photopic conditions with glare and between ACD and AULCSF under mesopic conditions with glare. A possible interpretation for these relationships might be that surgeons have a greater intraocular space in which to perform cataract surgery in patients with a larger WTW or deeper ACD, thus causing less injury to the eye tissue and resulting in better visual performance 1 month after surgery. There is a paucity of studies aimed at assessing the effect of the WTW and ACD on visual performance after MIOL implantation. Similar to our findings, Anh D et al. reported that a greater ACD increased the odds of a good postoperative outcome in phacoemulsification [25]. However, both the WTW and ACD were also positively associated with IOL decentration, which could deteriorate the patient's postoperative visual quality. Clinicians must consider the dual effects of both the WTW and the ACD. The equilibrium of these dual natures and the reliability of these interactions remain to be elucidated by further study.

We also observed that IOL power had a positive relationship with CDVA; namely, lower IOL power predicted worse CDVA. It is well known that lower IOL power is always observed in myopic eyes. Patients with high myopia often experience poorer CDVA and impaired quality of life, despite having no history of any high myopia-related complications [26,27].

5. Limitations

The current study has several limitations. We could enroll only 72 eyes in our evaluation, and future studies with larger sample sizes are warranted to validate our initial findings. Second, the retrospective nature of the study led to the absence of some preoperative ocular biometric parameters, including lens thickness, preoperative pupil size, angle α and angle κ, which might have influenced the statistical analysis. Moreover, there was no control group using other MIOLs, so whether the correlations demonstrated in the current study are specific to the Diff-aAY IOL or are applicable for all MIOLs cannot be determined.

6. Conclusions

In conclusion, our study showed that younger age predicted higher MTF and PSF values, better AULCSF and lower retinal straylight. A lower corneal trefoil resulted in better MTF and PSF values, while a smaller IOL decentration was accompanied by better DCNVA, greater AULCSF and better retinal straylight. A less negative SE induced better MTF values, and a more negative SE induced better VF-14 scores and satisfaction scores. A higher IOL power predicted better CDVA while lower preoperative corneal astigmatism predicted higher MTF values. Lower postoperative corneal astigmatism, smaller corneal HOAs, smaller photopic pupil size, larger WTW and deeper ACD were accompanied by a higher AULCSF. Clinicians can benefit from these findings, which can help detect patients at high risk of reporting dissatisfaction after surgery and assist in optimal treatment decisions.

Ethics approval

This study complied with the guidelines of the Declaration of Helsinki and was approved by the ethics committee of the Eye and ENT Hospital of Fudan University (2013021). The subjects were fully informed and provided written consent.

Data availability statement

The data will be made available on request.

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CRediT authorship contribution statement

Jie Xu: Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Fan Yang:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Peimin Lin:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Dongjin Qian:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Tianyu Zheng:** Writing – review & editing, Supervision, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31867.

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