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Research Article

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Correlative Analysis of Optical Quality Parameters Measured by OPD-Scan III in Primary Open-Angle Glaucoma

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ABSTRACT

Objective: This study aimed to analyse visual quality and its associated factors in patients with primary open-angle glaucoma (POAG) using OPD-Scan III. **Methods:** In this retrospective study, 53 eyes from patients with POAG were enrolled and divided into an early-to-moderate stage group (22 eyes) and an advanced stage group (31 eyes). All subjects underwent optical coherence tomography, visual field testing, and ocular biometry. Higher-order aberrations (HOAs) and the modulation transfer function (MTF) were analysed using OPD-Scan III. Spearman correlation analysis was performed to assess the relationships between MTF values at spatial frequencies of 5–30 cycles per degree (cpd) and visual field mean deviation (MD) as well as average retinal nerve fiber layer thickness (RNFLT). **Results:** At a 4-mm pupil diameter, no statistically significant difference in HOAs was found between the two groups (all $P>0.05$). However, a significant intergroup difference was observed in MTF values at the 5 cpd spatial frequency ($U=4.394$, $P=0.036$), while no significant differences were found at other spatial frequencies (all $P>0.05$). MTF values at spatial frequencies of 5, 10, and 15 cpd each showed positive correlations with MD ($r=0.345$, $P=0.011$; $r=0.318$, $P=0.020$; $r=0.330$, $P=0.016$, respectively). **Conclusion:** MTF values at the 5 cpd spatial frequency were significantly reduced in advanced POAG patients. The decline in MTF within the 5–15 cpd range was significantly correlated with the progression of visual field defects. These findings highlight the importance of emphasizing the assessment and intervention of visual quality in the management of advanced POAG.

Keywords: Primary open-angle glaucoma; Visual field; Average retinal nerve fiber layer thickness; OPD-Scan III; Modulation transfer function

1 Introduction

Primary open-angle glaucoma (POAG) is an ophthalmic disease characterized by progressive optic nerve atrophy and characteristic visual field (VF) defects. It has become a leading cause of blindness and moderate/severe visual impairment worldwide [1, 2]. As the disease progresses, the decline in patients' visual quality can easily induce or exacerbate symptoms of anxiety and depression, thereby affecting their quality of life [3, 4].

Optical coherence tomography (OCT) and VF examination are widely used and complementary techniques for diagnosing and assessing the progression of POAG [5]. Previous studies have shown that mean deviation (MD) is an independent risk factor for vision-related quality of life abnormalities in POAG patients [6]. However, this indicator cannot predict the impact of glaucoma severity on object recognition and classification abilities, making it difficult to accurately reflect visual quality, thus presenting limitations in clinical application[7].

In recent years, OPD-Scan III has been applied in refractive correction and cataract surgery to assess objective indicators such as higher-order aberrations (HOAs) and the modulation transfer function (MTF). Its measurements show good repeatability and results that closely approximate the true state of the human eye [8]. MTF can objectively describe the optical changes in visual quality at different spatial frequencies, providing

a more accurate assessment of imaging quality. The high-frequency region corresponds to the ability to resolve fine details, the medium-frequency region reflects the perception of object layers, and the low-frequency region relates to the recognition of object contours [9].

Surgical intervention remains a crucial means for controlling intraocular pressure and delaying the progression of VF defects in glaucoma management. In recent years, with the widespread adoption of refractive cataract surgery, POAG patients with concomitant cataracts often undergo combined glaucoma and cataract surgery to control disease progression and improve visual function. However, patients with advanced POAG have irreversible optic nerve damage, and the characteristics of their visual system significantly differ from those of patients with age-related cataracts. Therefore, the selection of intraocular lenses in combined surgery requires differentiated consideration. This study aims to use OPD-Scan III to detect the objective visual quality of POAG patients and explore the correlation between POAG progression and MTF values at different spatial frequencies. The goal is to provide data and a theoretical basis for developing individualized treatment plans to improve the visual quality of patients with advanced POAG.

2 Materials and Methods

1. Subjects and Methods

1.1 Subjects

Inclusion criteria: ① Patients diagnosed with POAG according to the Chinese

Glaucoma Guidelines [10] and staged using the international VF staging method (Hodapp-Parrish-Anderson, H-A-P) [11] : Early stage: MD ≥ -6 dB; Moderate stage: -12 dB ≤ MD < -6 dB; Advanced stage: MD < -12 dB; ② Intraocular pressure ≥ 21 mmHg (1 mmHg = 0.133 kPa) and no history of ocular surgery; ③ Clear and open anterior chamber angle structure.

Exclusion criteria: ① Patients unable to cooperate with ophthalmic examinations; ② Other types of glaucoma; ③ History of other ocular diseases or trauma; ④ Presence of severe systemic diseases.

Data from 30 patients (53 eyes) with POAG consecutively admitted to Shijiazhuang People's Hospital from September 2023 to March 2025 were collected and divided into early-to-moderate and advanced stage groups. This study adhered to the tenets of the Declaration of Helsinki, and all participants provided informed consent.

1.2 Methods

1.2.1 General Examination

All patients underwent slit-lamp microscopy examination; fundus examination was performed using a digital wide-field lens (Volk, USA) and an ophthalmoscope; and gonioscopy was performed using a goniolens (Volk, USA).

1.2.2 OCT Examination

The Spectralis OCT (Heidelberg Engineering, Germany) retinal nerve fiber layer (RNFL) scan protocol was used. A circular scan centered on the optic disc with a diameter of 3.4 mm was performed to measure and record the average retinal nerve fiber layer thickness (RNFLT).

1.2.3 VF Examination

VF testing was conducted using the Humphrey Field Analyser (750i, Carl Zeiss Meditec, Germany) with the 30-2 program and the SITA-Standard strategy. A test was considered reliable if the fixation loss rate was <20%, and both false-positive and false-negative rates were <15%. The MD value was recorded.

1.2.4 Biometric Parameter Measurement with IOL-Master 700

Ocular biometric parameters were measured using the IOL-Master 700 (Carl Zeiss Meditec, Germany). Examinations were performed under natural pupil conditions. The patient's head was kept upright, the chin was placed on the chin rest, and the forehead was placed against the headrest. The patient kept both eyes wide open and focused on the fixation target inside the instrument. Measurements were analysed and recorded after each blink. Axial length (AL), lens thickness (LT), and mean keratometry (Km) were recorded.

1.2.5 Measurement with OPD-Scan III

The OPD-Scan III (NIDEK, Japan) was used. In a dark room environment, subjects maintained their natural pupil size, kept both eyes wide open, and focused on the target in the measurement window. The examiner manipulated the joystick for alignment and focus adjustment before initiating the measurement. Three consecutive measurements were taken. The pupil analysis diameter was set to 4.0 mm. Photopic pupil diameter, mesopic pupil diameter, distance of photopic angle kappa (PDist), distance of mesopic angle kappa (MDist), total eye HOAs, internal HOAs, and corneal HOAs under a 4 mm pupil diameter were measured. MTF values at spatial frequencies from 0 to 60 cpd were

recorded.

1.3 Statistical Analysis

This was a retrospective study. Data analysis was performed using SPSS 27.0 software. Continuous variables conforming to a normal distribution are presented as $\bar{x} \pm s$, while those not conforming to a normal distribution are presented as $M(Q_1, Q_3)$. Intergroup comparisons of normally distributed and non-normally distributed measurement data were conducted using independent samples t-tests and Mann-Whitney U tests, respectively. Categorical variables were compared using the chi-square test. Spearman correlation analysis was used to analyse the correlations between MD, average RNFLT, and MTF values at spatial frequencies of 5-30 cpd under a 4 mm pupil diameter. A P value < 0.05 was considered statistically significant.

3 Results

2.1 General Characteristics

A total of 53 eyes from POAG patients were divided into an early-to-moderate group (22 eyes) and an advanced group (31 eyes). Statistically significant differences were found in MD and average RNFLT between the two groups (both $P < 0.001$). No statistically significant differences were observed in age, gender ratio, AL, LT, or Km (all $P > 0.05$). (Table 1)

2.2 Comparison of Objective Visual Quality Parameters Between the Two Groups

No statistically significant differences were found between the two groups in Total eye HOAs, Corneal HOAs, or Internal HOAs (all $P > 0.05$). (Table 2)

2.3 Comparison of MTF Values at Different Spatial Frequencies Between the Two Groups

Under a 4 mm pupil diameter, a statistically significant difference in MTF values at the 5 cpd spatial frequency was found between the two groups (U=4.394, P=0.036). No statistically significant differences were found in MTF values at spatial frequencies from 10 to 30 cpd (all $P > 0.05$). (Table 3, Fig 1)

2.4 Correlation Analysis Between MD, Average RNFLT, and MTF Values at Various Spatial Frequencies in POAG Patients

In POAG patients, under a 4 mm pupil diameter, MTF values at spatial frequencies of 5-15 cpd showed positive correlations with MD (r=0.345, P=0.011; r=0.318, P=0.020; r=0.330, P=0.016). Similarly, under a 4 mm pupil diameter, MTF values at spatial frequencies of 5-15 cpd showed positive correlations with average RNFLT (r=0.298, P=0.030; r=0.286, P=0.038; r=0.277, P=0.044). (Table 4)

Table 1. Comparison of baseline Data between Two Groups of POAG Patients

Variables	⩾-12dB	<-12dB	$T/U/\chi^2$	*P*
Age(year)	62.32±2.31	63.16±2.00	-0.275[a]	0.784
Sex (Male/Famale)	13/9	22/9	0.809[b]	0.368
Average RNFLT(μm)	82.64±3.24	48.29±1.71	9.379[a]	<0.001[*]
MD(dB)	-5.30±0.60	-24.62(-29.61, -18.54)	37.889[c]	<0.001[*]
AL(mm)	23.92±0.28	23.83±0.27	0.249[a]	0.804
LT(mm)	4.44±0.11	4.73(4.47, 4.88)	2.582[c]	0.108
Km(D)	44.59±0.36	44.74±0.27	-0.343[a]	0.733
Photopic(mm)	3.46(3.11, 3.61)	3.550(3.13, 3.75)	0.334[c]	0.563
PDist(mm)	0.23±0.02	0.30±0.03	-1.585[a]	0.119
Mesopic(mm)	4.63±0.17	4.58(4.19, 4.80)	0.496[c]	0.481
MDist(mm)	0.24±0.03	0.30±0.03	-1.474[a]	0.147

[a], Independent-Samples *T* Test; [b], Chi-square test; [c], Mann-Whitney *U* test; [*], $P<0.05$

RNFLT, Retinal Nerve Fiber Layer Thickness; MD, mean deviation; AL, axial length; LT, lens thickness; Km, mean keratometry

Table 2. Comparison of Total eye, Corneal, and Internal High-Order Aberrations Between the Two POAG Groups

Variables	≥-12dB	<-12dB	*U*	P^*
Total eye HOAs(μm)	0.248(0.178, 0.342)	0.297(0.232, 0.370)	2.881	0.090
Corneal HOAs(μm)	0.163(0.135, 0.230)	0.177(0.146, 0.206)	0.064	0.800
Internal HOAs(μm)	0.244(0.163, 0.257)	0.249(0.201, 0.314)	1.695	0.193

[*], $P>0.05$

Table 3 Comparison of the MTF Values at different spatial frequencies between Two Groups

Spatial frenquencies	≥-12dB	<-12dB	*U*	*P*
5cpd	0.246±0.040	0.140(0.010, 0.250)	**4.394**	**0.036***
10cpd	0.142±0.022	0.060(0.010, 0.110)	3.820	0.051
15cpd	0.060(0.020, 0.095)	0.040(0.000, 0.070)	3.789	0.052
20cpd	0.030(0.010, 0.073)	0.020(0.000, 0.040)	2.463	0.117
25cpd	0.020(0.010, 0.053)	0.020(0.000, 0.030)	1.909	0.167
30cpd	0.020(0.008, 0.040)	0.010(0.000, 0.030)	1.415	0.234
35cpd	0.010(0.000, 0.030)	0.010(0.000, 0.020)	1.200	0.273
40cpd	0.010(0.000, 0.022)	0.010(0.000, 0.020)	1.665	0.197
45cpd	0.010(0.000, 0.020)	0.010(0.000, 0.010)	1.243	0.265
50cpd	0.010(0.000, 0.020)	0.000(0.000, 0.010)	1.129	0.288
55cpd	0.005(0.000, 0.020)	0.000(0.000, 0.010)	1.833	0.176
60cpd	0.005(0.000, 0.013)	0.000(0.000, 0.010)	3.569	0.059

*, $P<0.05$

Table 4 Correlation between MD, Average RNFL Thickness and MTF Values at Various Spatial Frequencies in POAG Patients

Spatial	MD		Average RNFLT	
frenquencies	*r*	*P*	*r*	*P*
5cpd	**0.345**	**0.011***	**0.298**	**0.030***
10cpd	**0.318**	**0.020***	**0.286**	**0.038***
15cpd	**0.330**	**0.016***	**0.277**	**0.044***
20cpd	0.240	0.084	0.227	0.102
25cpd	0.256	0.064	0.209	0.133
30cpd	0.202	0.147	0.194	0.163

*, $P<0.05$

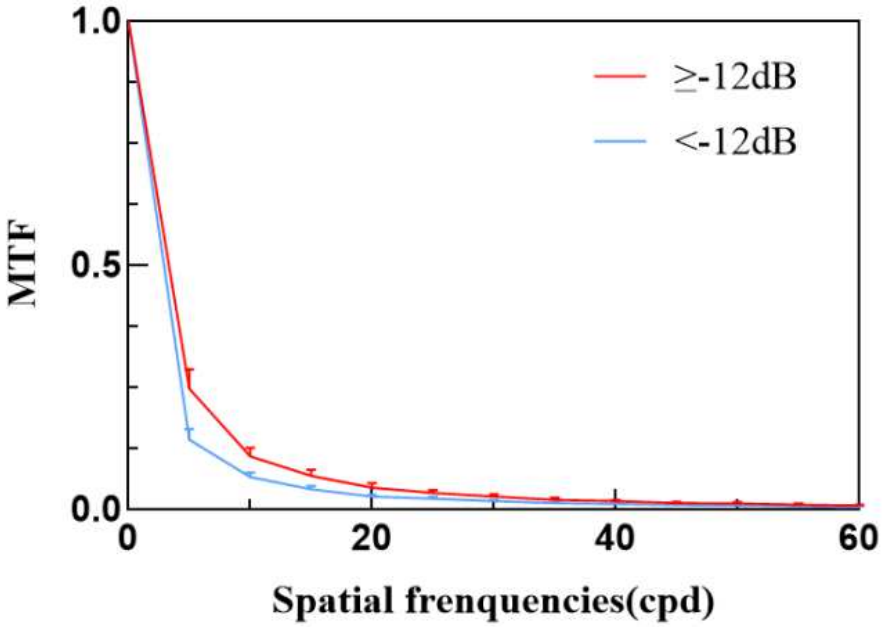


Fig 1. Comparison of the MTF Values at different spatial frequencies between Two Groups.

4 Discussion

The progression of POAG is often accompanied by the progressive loss of retinal ganglion cells and optic nerve damage. Clinically, it is characterized by narrowing of the neuroretinal rim, loss of the RNFL, and progressive VF defects [12]. Previous studies have confirmed that even glaucoma patients presenting only with peripheral VF defects exhibit impairments in visual information integration and parsing functions (such as scene recognition) [7, 13]. Particularly in low-contrast environments such as fog, strong glare, or shadows, patients' object recognition and classification abilities are significantly reduced. Even glaucoma patients without obviousVF defects have significantly weaker object classification abilities in real-world scenes compared to healthy individuals [13]. Therefore, during the clinical diagnosis and treatment of

glaucoma, it is essential to focus on patients' object recognition abilities at different spatial frequencies and dynamically monitor changes in visual quality to mitigate negative impacts on their quality of life and mental health.

This study used OPD-Scan III to assess the visual quality of POAG patients. The results showed no statistically significant differences in ocular biometric parameters or HOAs between early-to-moderate and advanced stage patients ($P > 0.05$). Under a 4 mm pupil diameter, MTF values at the 5 cpd spatial frequency were significantly higher in the early-to-moderate group than in the advanced group ($P < 0.05$), and MTF values in both groups decreased with increasing spatial frequency. Correlation analysis indicated that MTF values at spatial frequencies of 5-15 cpd were positively correlated with MD and average RNFLT. Low spatial frequencies primarily correspond to the recognition of overall image contours, large-area backgrounds, and low-contrast regions, while high spatial frequencies convey fine details and edge information. The findings of this study suggest that retinal photoreceptor function is partially preserved in early-to-moderate POAG patients, allowing them to maintain basic detail resolution capabilities. As the disease progresses, patients experience a decline in signal transmission at the 5 cpd spatial frequency and object recognition ability. Zhang Y et al. [14] assessed the visual quality of glaucoma patients using the Optical Quality Analysis System (OQAS) and reached similar conclusions. Their study showed that the MTF cut-off frequency was significantly negatively correlated with MD. The underlying mechanism may be that as the disease progresses, the RNFL gradually thins and retinal ganglion cells (RGCs) are damaged, thereby affecting the efficiency of optical signal transmission. This

mechanism aligns with the observed correlation between MTF values and MD/average RNFLT in our study. The research by Trouilloud A et al. [15] provides further support, confirming that early-stage glaucoma patients show no significant abnormalities in object recognition function across different spatial frequencies. However, as the disease progresses, the efficiency of the visual system in processing information across all spatial frequencies significantly declines, with a higher error rate for high spatial frequency information classification. This change is closely related to the progressive destruction of RGCs, corroborating the conclusions of our study and collectively revealing the intrinsic link between POAG progression and the decline in visual quality.

In the clinical treatment of glaucoma, surgical intervention remains crucial for controlling intraocular pressure and delaying the progression of VF defects. With the widespread adoption of refractive cataract surgery, POAG patients with concomitant cataracts have higher expectations for postoperative visual quality. Multiple studies have shown that multifocal intraocular lenses (IOLs) can improve postoperative visual quality in patients with cataracts alone to a certain extent [16, 17]. The results of this study indicate that the mesopic pupil diameter under dark conditions, kappa angle, and total eye HOAs under a 4 mm pupil diameter in early-to-moderate POAG patients meet the implantation criteria for such lenses [18-20]. Therefore, for glaucoma patients with cataracts who meet the corresponding optical conditions and have stable POAG, IOLs with good mid-to-low spatial frequency imaging performance can be selected to improve postoperative visual quality. However, clinical decision-making should strictly assess the degree of disease progression and individual visual needs, aiming to improve

visual quality while ensuring surgical safety.

De Moraes CG et al. [21], through comprehensive analysis, proposed that the progression of glaucomatous VF defects is closely related to the decline in health-related quality of life. Zhang Y et al. [14] used the Hospital Anxiety and Depression Scale (HADS) to assess the psychological status of POAG patients. Their research showed that HADS-Depression and HADS-Anxiety scores were significantly correlated with the NEI VFQ-25 score of the worse eye, suggesting the need for close attention to the psychological state of glaucoma patients in clinical practice. When conducting objective visual quality assessments, subjective evaluation methods should be combined for a comprehensive assessment of visual quality.

This study requires further expansion of the sample size. Moreover, HOAs and MTF can only reflect patients' visual quality at an objective level. Subsequent research will supplement subjective visual quality assessment indicators such as the NEI VFQ-25 questionnaire and contrast sensitivity to comprehensively analyse the impact of POAG progression on objective visual quality.

5 Conclusion

In conclusion, this study quantitatively assessed the visual quality of POAG patients using OPD-Scan III. The results showed that MTF values at the 5 cpd spatial frequency were significantly reduced in advanced POAG patients. Furthermore, MTF values in the 5-15 cpd spatial frequency range were positively correlated with MD. No statistically significant differences were found in ocular biometric parameters or HOAs

between POAG patients at different stages of progression. Therefore, in the clinical management of POAG, based on controlling disease progression, systematic assessment and targeted intervention for visual quality should be strengthened to improve patients' visual function and enhance their overall quality of life.

Abbreviations

POAG	Primary Open-Angle Gaucoma
OCT	Optical Coherence Tomography
VF	Visual Field
MD	Mean Deviation
HOAs	Higher Order Aberrations
MTF	Modulation Transfer Function
H-P-A	Hodapp-Parrish-Anderson
RNFL	Retinal Nerve Fiber Layer
RNFLT	Retinal Nerve Fiber Layer Thickness
AL	Axial Length
TL	Len Thickness
Km	mean Keratometry
PDist	Distance of Photopic angle Kappa
MDist	Distance of Mesopic angle Kappa
HADS	Hospital Anxiety and Depression Scale

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Author contributions

Conception and design of study: Hengli Zhang, Kuitang Shi; Acquisition of data: Kuitang Shi, Yulei Geng, Weijia Li, Guangxian Tang, Xiaowei Yan, Yawen Li, Tianyu Zhang, Jiaming Lu, Shuai Wang; Data analysis and interpretation: Kuitang Shi; Drafting of manuscript and critical revision: Yulei

Geng; Approval of final version of manuscript: Yulei Geng, Kuitang Shi. All authors approved the final manuscript and the submission to this journal.

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Data availability

The datasets utilized and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study has been approved by the Medical Research Ethics Committee of Shijiazhuang People's Hospital (No.2026-023). During the treatment consultation, comprehensive information was provided to all patients and their families, who voluntarily signed informed consent forms related to the treatment.The research complied with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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