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ORIGINAL RESEARCH

Assessment of Visual Function Using Yellow-Tinted Filter in Patients with Pre-Perimetric and Early Open Angle Glaucoma

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Purpose: This study aimed to assess the effect of an external yellow-tinted filter (KIROS 1–400 lens) on visual function in patients with pre-perimetric glaucoma (PPG) and early primary open-angle glaucoma (POAG). The primary outcomes were contrast sensitivity (CS) and visual field (VF) indices assessed using standard automated perimetry (SAP).

Methods: This comparative observational, within-subject study included 30 patients with PPG (30 eyes) and 50 with POAG (50 eyes) recruited from the Ophthalmology Department of the 401 General Military Hospital, Athens, between January and December 2022. CS was measured using the Pelli-Robson chart. VF indices, including mean deviation (MD), pattern standard deviation (PSD), visual field index (VFI), and Glaucoma Hemifield Test (GHT) classifications, were assessed with SAP with the 24–2 SITA-standard strategy on the Humphrey Field Analyzer II 740. All testing was performed both with and without the yellow filter KIROS 1–400 (Essilor International) in the same eyes.

Results: The KIROS 1–400 filter significantly enhanced CS in both PPG and POAG eyes, increasing the median logCS by 0.03. However, while statistically significant, this improvement may not be clinically meaningful. In contrast, no significant changes were observed in the VF indices (MD, PSD, and VFI) when the filter was applied. Analysis of GHT results revealed that the filter reduced borderline classifications and showed high precision (0.733) and recall (0.846) for "outside normal limits" classifications. However, the agreement between the filtered and unfiltered GHT results was fair.

Conclusion: The KIROS 1–400 filter significantly enhanced CS in patients with PPG and POAG without notable effects on the VF indices. However, caution is advised when interpreting GHT results obtained with yellow-tinted filters. Further studies are recommended to evaluate the filter's long-term clinical benefits and its potential role in glaucoma management.

Keywords: visual function, visual field, contrast sensitivity, yellow-tinted filter, pre-perimetric glaucoma, early glaucoma

Introduction

Colored filters designed to selectively block specific segments of the visible light spectrum are proposed interventions for improving visual function in patients with low vision. These filters reduce severe photophobia, enhance contrast sensitivity (CS), and improve blurred vision and reduced visual acuity (VA).[1] Yellow-tinted filters absorb high-energy blue light (380–500 nm) using a yellow chromophore, potentially influencing specific visual pathways. Notably, the koniocellular pathway, which processes blue-yellow light and is active within this wavelength range, is affected in the early stages of glaucoma.[2,3] This raises the possibility that yellow-tinted filters may have a measurable impact on visual function, including visual field (VF) indices, in patients with glaucoma.

Glaucoma is a progressive optic neuropathy characterized by damage to retinal ganglion cells and their axons, leading to VF defects.[4] Standard automated perimetry (SAP) using the white-on-white method is considered the gold standard for

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assessing VF defects in glaucoma and serves as a reference for other methods.[5] However, the potential influence of yellow-tinted filters on SAP performance in patients with glaucoma, particularly those with pre-perimetric and early perimetric glaucoma, remains underexplored.

A review by Eperjesi et al[6] evaluated the effects of various colored filters on the visual function of patients with different ocular conditions. While some studies have reported improvements in VA, CS, and dark adaptation, the evidence is inconsistent owing to methodological limitations and contradictory findings. Specifically, for glaucoma, the review highlighted patient-specific preferences for tinted filters aimed at addressing photophobia and glare sensitivity. Hoeft and Hughes,[7] as cited in the review, observed that patients with glaucoma preferred filters with higher light transmission levels, such as 18% (Grey-Green) and 10% (Amber). In contrast, individuals with conditions such as retinitis pigmentosa or albinism favored filters with lower light transmission levels (eg, 2% and 10%, respectively). This preference likely reflects the need to balance glare reduction with the preservation of CS and visual function in patients with glaucoma. However, these observations were primarily derived from subjective patient feedback rather than rigorous clinical evidence, limiting their applicability in clinical practice.

CS is consistently reduced in glaucomatous eyes, even in early stages, and is more pronounced under low-luminance conditions, contributing to real-world functional difficulties such as reading, object recognition, and other daily activities.[8] Importantly, glare sensitivity (photophobia) has been identified as one of the most frequently reported and impactful symptoms, affecting over half of glaucoma patients across multiple studies. These symptoms are closely linked to difficulties with driving, adapting to lighting transitions, and general visual discomfort, and are evident even in patients with mild or early-stage glaucoma. Yellow-tinted filters may offer a practical, non-invasive approach to mitigate these under-recognized functional limitations by enhancing visual comfort and performance across varied lighting environments.

Our group previously investigated the effects of two filters, KIROS 1–400 and Lumior 1–400 (Essilor International, Charenton-le-Pont, France), on VF indices and CS in healthy individuals.[9] Both filters, with visible light transmission (VLT) of 75% and 65%, respectively, align with the preferences of patients with glaucoma for higher VLT levels while selectively targeting the koniocellular pathway. The study demonstrated a significant improvement in photopic CS measures without any impact on VF performance. These findings highlight the potential clinical benefits of yellow-tinted filters and provide a basis for further exploration of their applicability in patients with glaucoma.

This study aimed to evaluate the effects of the yellow-tinted KIROS 1–400 filter on visual function in patients with pre-perimetric and early glaucoma. The study examined whether the filter, designed to target key visual pathways and align with patient preferences for high VLT levels, impacted SAP and CS outcomes.

Methods

Study Participants

This comparative study involved 30 eyes of 30 patients with pre-perimetric glaucoma (PPG) and 50 eyes of 50 patients with primary open-angle glaucoma (POAG) who visited the Ophthalmology Department of the 401 General Military Hospital of Athens, Greece, between January and December 2022.

The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the Ethics and Research Ethics Committee of the University of West Attica (approval protocol number: 36659/Apr 27, 2021) and the Scientific Council of the 401 General Military Hospital of Athens (meeting protocol number: 05/Jun 02, 2020). Informed consent was obtained from all participants.

Participants were diagnosed with PPG or early POAG. When both eyes of a patient were eligible based on the inclusion and exclusion criteria, one eye was randomly selected for analysis. PPG was defined by the presence of glaucomatous-appearing optic discs (eg, neuroretinal rim notching or thinning or a retinal nerve fiber layer [RNFL] defect) and/or abnormal circumpapillary RNFL (cpRNFL) thickness in at least one sector (based on the 12-sector or 36-sector grid), as measured by optical coherence tomography (OCT), with normal 24–2 VF test results confirmed on two separate occasions. An abnormal (red-colored) sector was defined as an RNFL thickness below the first percentile of normative database values.

Early POAG was defined by at least two consecutive abnormal 24–2 VF test results and evidence of glaucomatous optic disc changes. Eyes were classified as early POAG according to the Hodapp-Parrish-Anderson VF criteria,[10] which

specify a mean deviation (MD) between 0 and −6 dB, along with at least one of the following: (a) a glaucomatous VF defect, indicated by a glaucoma hemifield test (GHT) outside normal limits (ONL) on at least two VFs; (b) a cluster of three or more non-edge points depressed on the pattern deviation plot ($p < 5\%$), including at least one point depressed at the $p < 1\%$ level; or (c) a pattern standard deviation (PSD) with $p < 5\%$.

Inclusion criteria included: (a) male or female aged 18–80; (b) reliable VF testing (≤33% false positives, false negatives, fixation losses); (c) willingness to attend study visits and provide informed consent; (d) normal or elevated IOP; and (e) one or both eyes meeting criteria for PPG or early POAG.

Participants were excluded if they had: (a) a history of amblyopia; (b) corrected VA below 0.2 logMAR (20/30) if aged 50 or older, or below 0.1 logMAR (20/25) if under 50; (c) refractive error exceeding 5 D spherical equivalent or 1.0 D cylinder; (d) significant ophthalmic disease (other than POAG for the respective group), significant trauma, or prior intraocular surgery (with the exception of glaucoma surgery for POAG or uncomplicated cataract surgery); (e) abnormal pupil size or reactivity, or medications affecting pupil size; (f) systemic diseases or medications expected to affect VF; (g) a history of stroke, insulin-dependent diabetes, or diabetic retinopathy; and (h) clinically significant lenticular opacity, defined using the Lens Opacities Classification System III (LOCS III) as any of the following: nuclear opalescence (NO) exceeding grade 2, nuclear color exceeding grade 2, cortical cataracts (C) exceeding grade 2, or posterior subcapsular cataracts exceeding grade 1.[11] All pseudophakic participants had undergone cataract surgery with implantation of the AcrySof® IQ Monofocal intraocular lens (Alcon Laboratories), which incorporates a blue-light filtering chromophore, ensuring consistency in IOL characteristics across subjects.

After enrolling approximately half of our patients and obtaining initial results, we performed a revised sample size calculation using G*Power software (Heinrich University Düsseldorf, Düsseldorf, Germany). Based on this interim analysis, using an effect size of 0.5, a type I error probability of 0.05, and a study power of 0.90, we estimated that a total sample size of 21 patients with PPG and 34 patients with POAG would be required.

Measurements

Each recruited patient underwent a comprehensive ophthalmological examination that included (a) detailed medical history, (b) best-corrected visual acuity (BCVA) assessment using a digital Snellen chart, (c) slit-lamp biomicroscopy, (d) intraocular pressure (IOP) measurement with a Goldmann tonometer, and (e) VF and CS evaluations.

All eligible patients participated in a practice session before formal testing to familiarize themselves with the procedures and minimize learning effects during actual measurements. The study visit was scheduled one week after the practice session. During this visit, one eye from each participant underwent the following examinations, both with and without the yellow KIROS 1–400 filter: (1) VF testing using the SAP (24–2, SITA-standard strategy) with the Humphrey Field Analyzer II 740 (Carl Zeiss Meditec, Jena, Germany) and (2) CS assessment using the Pelli-Robson (PR) chart (Precision Vision, Inc., Woodstock, IL) (chart 3).

Due to the visible tint of the KIROS 1–400 filter, masking of the examiner and participants was not possible. To reduce bias, the order of testing (with and without the filter) was randomized and kept consistent for each participant. All measurements followed standardized, objective protocols for both SAP and contrast sensitivity testing. To further reduce variability, participants were given adequate rest periods (at least five minutes) between tests to minimize fatigue-related influences on subsequent measurements. During CS assessment, participants were encouraged to observe the letters for at least 20 seconds, as this is often necessary for perception at the threshold level.[12]

The Yellow Filter Kiros 1-400

In the recent study by our group,[9] the filters were cut using an automated ophthalmic lens wheel and mounted into a specialized metal housing for use with the Humphrey Field Analyzer in VF testing. They were also adapted for use in a trial lens frame for the CS assessment.

In the current study, we employed the same methodology using the KIROS 1–400 filter for both SAP and CS assessments. The filter was prepared in the same manner and mounted into a compatible housing to maintain consistency across studies. The KIROS 1–400 filter is a yellow-tinted filter designed to block blue light transmission up to 400 nm while selectively transmitting wavelengths near the eye's peak sensitivity (555 nm). With a VLT of 75%, the filter was classified as

a Category I filter, providing limited protection from sun glare (VLT range: 43%–80%). It also provides 100% UVA and UVB protection, features 50% VLT at 475 nm, and is made of spherical plastic Orma UVX material with an index of refraction of 1.502, an Abbe number of 58, and a density of 1.32. Additionally, the filter was equipped with an antireflective coating.

The manufacturer claims that the KIROS 1–400 filter provides maximum UV protection, enhances CS, improves visual comfort, and may even improve VA in some cases. However, these claims are yet to be substantiated by supporting studies.[13–17]

SAP and Contrast Sensitivity Measurements

SAP was performed using a Humphrey Field Analyzer II 740 (Carl Zeiss Meditec, Jena, Germany) with the 24–2 SITA-standard strategy. A white stimulus of size III (4 mm^2) was applied to a white background with a luminance intensity of 31.5 apostilbs (asb). The GHT, MD, PSD, and visual field index (VFI) were recorded. All the participants had prior experience with VF testing. The KIROS filter was inserted into the holder for VF testing and used in the same manner as standard trial lenses.

For CS assessment, a uniformly illuminated PR wall chart (Chart 3) was employed, with a brightness of 92.6 cd/ m^2. The participants were positioned at a distance of 1 meter from the chart to ensure alignment of eye height with the center of the diagram. The optimal distance correction was applied, with an additional +0.75 diopters (dpt) added when necessary. The chart comprises large Sloan letters in triplets, each decreasing in contrast by 0.15 log units, from 100% to 0.56% contrast (log contrast spanning 0.00 to 2.25). A participant passed each contrast level by correctly identifying at least two of the three letters in a triplet. A letter-by-letter scoring system was employed, assigning 0.05 points to each correctly identified letter. Testing was concluded when the participant failed to identify at least two of the three letters in a triplet.

Statistical Analysis

Distribution testing was performed using the Kolmogorov–Smirnov and Shapiro–Wilk tests and visual inspection of histograms. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 21 (IBM SPSS Statistics, Armonk, NY). Quantitative variables with a normal distribution were evaluated using paired-sample *t*-tests. The Wilcoxon test was applied to quantitative, ordinal, and discrete variables that did not meet the normality assumption. Variables following a normal distribution are presented as mean values with standard deviations (SD), whereas nominal variables were assessed using the Cochrane Q test and are reported as median values with interquartile ranges (IQR). For a more in-depth analysis of the GHT classification results, a confusion matrix was generated to compare the GHT classifications with and without the KIROS 1–400 filter. The analysis was performed using the online tool developed by Perri et al[18,19] Statistical significance was set at a p-value of <0.05. No adjustment for multiple comparisons was performed, as the analyses focused on a small number of pre-specified primary outcomes.

Results

The study included 30 eyes of 30 patients with PPG and 50 eyes of 50 patients with POAG. Patients with inadequate reliability of the SAP VF test were excluded from the analysis. The demographic and clinical characteristics of the participants are summarized in Table 1.

Table 1 Demographic and Clinical Characteristics of Study Population

Parameter	Results	
	PPG	POAG
Age (years)	53.80 (16 to 64)	67.00 (59.75 to 73.25)
Sex (male/ female)	25/5	23/27
Eye (right/ left)	13/17	29/21

(*Continued*)

Table 1 (Continued).

Parameter	Results	
	PPG	POAG
Lens/ IOL	25/5	33/17
Medications (1/2/3/4)	29/1/0/0	25/13/10/2
Sphere (D)	0.00 (−0.81 to 0.31)	−0.25 (−0.50 to 1.31)
Cylinder (D)	0.00 (−0.50 to 0.00)	−0.50 (−1.00 to 0.00)
Spherical equivalent (D)	−0.25 (−0.81 to 0.00)	0.00 (−0.56 to 1.00)
BCVA (logMAR)	0.00 (0.00 to 0.00)	0.04 (0.10 to 0.00)

Note: All data are expressed in median (IQR).
Abbreviations: BCVA, best-corrected visual acuity; D, diopter; logMAR, logarithm of the minimal angle of resolution; IQR, inter-quartile range; IOL, intraocular lens; POAG, primary open-angle glaucoma; PPG, pre-perimetric glaucoma.

Visual Field Testing

Table 2 compares the VF indices and CS values in the PPG eyes, both with and without the use of the KIROS 1–400 lens. The analysis revealed no statistically significant differences in MD, PSD, or VFI, suggesting that the KIROS 1–400 filter did not affect the VF testing performance in PPG eyes.

Similarly, Table 3 shows no statistically significant differences in the VF indices for eyes with POAG when the KIROS 1–400 filter was used.

Table 4 presents the distribution of the GHT classifications before and after the application of the KIROS 1–400 filter. Although the yellow filter led to reclassification of glaucoma severity in a small number of eyes, the changes in the GHT results were not statistically significant.

To further evaluate the influence of the KIROS 1–400 filter on the classification of early POAG cases based on GHT, a confusion matrix is presented in Table 5. This matrix compares the GHT classifications with and without the KIROS 1–400 filter, enabling an assessment of how the filter affects the categorization of the three GHT outcomes: Within Normal Limits (WNL), Borderline, and ONL.

The KIROS 1–400 filter demonstrated the highest precision for the ONL category (0.733), indicating its strong ability to accurately identify true ONL cases without the use of a filter (Table 6).[18]

The precision for WNL was moderate (0.500), while Borderline cases showed the lowest precision (0.333). Similarly, recall (the number of cases identified using the yellow filter) was the highest for ONL (0.846), followed by WNL (0.583), and

Table 2 Comparison of SAP Indices and CS Values in Pre-Perimetric Glaucoma Eyes, Both with and without the Use of the KIROS 1–400 Filter

Variable	No Filter	Kiros 1–400	Z/ t Value	p-Value
MD (dB)†	−0.31 (0.75)	−0.20 (0.79)	−0.83 *	0.42 **
PSD (dB)†	1.52 (0.23)	1.48 (0.25)	1.10 *	0.29 **
VFI (%)‡	99 (99 to 100)	99 (99 to 100)	−0.89 ***	0.42 ****
CS (logCS)†	1.66 (0.08)	1.69 (0.08)	3.00 *	0.01**

Notes: †Results are presented as mean (SD); ‡Results are presented as median (IQR); * t-value; ** Paired Samples *t*-Test, Statistical significance was set at p<0.05; *** Z= value; **** Wilcoxon Signed Rank Test; Statistical significance was set at p< 0.05.
Abbreviations: CS, contrast sensitivity; IQR, inter-quartile range; MD, mean deviation; log, logarithm; PSD, pattern standard deviation; SAP, standard automated perimetry; SD, standard deviation; VFI, visual field index.

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Table 3 Comparison of SAP Indices and CS Values in POAG Eyes, Both with and without the Use of the KIROS 1–400 Filter

Variable	No Filter	KIROS 1–400	Z-Value	p-Value*
MD (dB)	−2.19 (−3.82 to −1.43)	−2.36 (−4.66 to −1.20)	1.35	0.18
PSD (dB)	2.50 (2.01 to 4.25)	2.74 (1.98 to 4.90)	−1.1	0.26
VFI (%)	96 (92 to 97)	96 (91 to 98)	0.46	0.56
CS (logCS)	1.52 (1.45 to 1.60)	1.55 (1.50 to 1.65)	−4.4	< 0.001

Notes: Results are presented as median (IQR); * Wilcoxon Signed Rank Test; Statistical significance was set at $p<0.05$.
Abbreviations: CS, Contrast sensitivity; MD, Mean Deviation; POAG, Primary Open Angle Glaucoma; PSD, Pattern standard Deviation; SAP, Standard Automated Perimetry; VFI, Visual Field Index.

Table 4 Comparison of GHT Results for Pre-Perimetric Glaucoma and POAG Eyes, Both with and without the Use of the KIROS 1–400 Filter

		ONL	Borderline	WNL	Z- Value	p- Value*
PPG	NF	0	4	26	0.38	0.71
	KIROS	0	3	27		
POAG	NF	26	12	12	−0.1	0.66
	KIROS	30	6	14		

Note: * Wilcoxon Signed Rank Test, Statistical significance was set at $p<0.05$.
Abbreviations: GHT, Glaucoma Hemifield Test; KIROS, The Yellow Kiros 1–400 filter; NF, No Filter; ONL, Outside Normal Limits; POAG, Primary Open Angle Glaucoma; PPG, Pre-perimetric Glaucoma; WNL, Within Normal Limits.

Table 5 POAG Eyes. Confusion Matrix of GHT Classification with and without the Use of the KIROS 1–400 Filter

		without the KIROS (true)			Total
		WNL	Borderline	ONL	
With the KIROS (predicted)	WNL	7	3	4	14
	Borderline	4	2	0	6
	ONL	1	7	22	30
Total		12	12	26	50

Abbreviations: GHT, Glaucoma Hemifield Test; Outside Normal Limits, ONL; WNL, Within Normal Limits.

Table 6 Summary of the Statistical Analysis Results for the Confusion Matrix of Each GHT Classification Category After Applying the KIROS 1–400 Filter

	Precision	1-Precision	Recall	1-Recall	F1 score
WNL	0.500	0.500	0.583	0.417	0.538
Borderline	0.333	0.667	0.167	0.833	0.222
ONL	0.733	0.267	0.846	0.154	0.786
Accuracy	0.620				

(*Continued*)

Table 6 (Continued).

	Precision	1-Precision	Recall	1-Recall	F1 score
Misclassification Rate	0.380				
Macro-F1	0.515				
Weighted-F1	0.591				

Abbreviations: GHT, Glaucoma Hemifield Test; ONL, Outside Normal Limits; WNL, Within Normal Limits.

lowest for Borderline categories (0.166), highlighting the filter's superior performance in detecting ONL cases compared to WNL and Borderline categories. A Cohen's kappa statistic of 0.358 (95% CI: 0.162–0.554) indicated fair agreement between the classifications before and after applying the KIROS 1–400 filter. This suggests that while the filter led to some reclassification, it did not introduce significant misclassification by chance. These findings highlight that the KIROS 1–400 filter had a notable impact on diagnostic classification, particularly by reducing the number of eyes classified as Borderline, while preserving robust accuracy for ONL cases.

Contrast Sensitivity

Tables 2 and 3 present the results of the pairwise comparisons for CS scores in PPG (Table 2) and POAG (Table 3) eyes, both with and without the KIROS 1–400 filter. Both glaucoma groups demonstrated significant improvements in the CS scores when the KIROS 1–400 filter was used.

Discussion

Our results suggest that the yellow-tinted Kiros 1–400 filter had a non-significant effect on VF indices, including MD, PSD, GHT, and VFI, in patients with PPG and early POAG. However, significant improvement in CS was observed in both patient groups. To the best of our knowledge, this is the first study to investigate the effects of external filters with higher VLT levels on visual function parameters in patients with glaucoma. While previous research has primarily focused on the impact of intraocular yellow-tinted lenses on visual function in patients with cataracts, the potential influence of external filters with varying VLT levels remains underexplored—particularly in patients with glaucoma.

In the PPG cohort, application of the Kiros 1–400 filter led to a slight, non-significant increase in MD and a minimal, non-significant decrease in PSD. Conversely, in the POAG cohort, a small decline in MD (−0.17 dB) and a minor increase in PSD (+0.24 dB) were noted, although these changes also failed to achieve statistical significance. The VFI remained unchanged across both groups. Regarding GHT classification, the filter's effect was primarily evident in the reclassification of borderline cases without introducing systematic misclassification. These findings suggest that while the KIROS 1–400 filter does not significantly alter VF indices, it offers a measurable improvement in CS, highlighting its potential as an adjunctive intervention for enhancing functional vision in patients with glaucoma.

The absence of statistically significant effects on the VF indices (MD, PSD, VFI, and GHT) across both groups can be attributed to several factors. First, the human visual system exhibits peak sensitivity to light at approximately 555 nm,[16] which may explain why the KIROS 1–400 filter did not significantly affect VF performance. The filter is specifically designed to block blue light transmission up to 400 nm while selectively transmitting wavelengths closer to the eye's peak sensitivity (555 nm). Moreover, the 25% reduction in blue light transmission by the Kiros 1–400 filter may not be substantial enough to clinically impact VF indices. This is in line with established preferences among patients with glaucoma for filters that allow a higher VLT. Specifically, patients with POAG often select filters that preserve CS and visual function while minimizing glare. Patients with POAG preferentially select filters with 18% (model 102) and 10% (model 101) light transmission.[7,20] It can be speculated that these preferences reflect the notion that filters with higher VLT may have a minimal impact on VF performance, as they allow adequate light transmission to preserve visual clarity. Consequently, the Kiros 1–400 filter, with its 25% cutoff radiation, likely did not attenuate light to a level that would substantially affect the VF indices.

As our study exclusively assessed the impact of the yellow-tinted KIROS 1–400 external filter on SAP VF parameters in patients with pre-perimetric and early glaucoma, it is important to acknowledge the absence of directly comparable studies on external filters. Consequently, comparisons have been drawn from the available literature on yellow-tinted intraocular lenses (IOLs) and their effects on VF outcomes using different perimetric methods, including SAP, short-wavelength automated perimetry (SWAP), and frequency doubling technology (FDT).

Studies examining yellow-tinted IOLs have provided indirect yet relevant insights. In healthy eyes, Kara-Júnior et al[21] observed no significant differences in the SWAP MD or PSD values between clear and yellow-tinted IOLs implanted in fellow eyes, suggesting minimal interference from lens coloration. Similarly, Jang et al[22] found no significant differences in SAP MD or PSD values between tinted and non-tinted IOLs. However, they reported significant differences in MD and PSD for SWAP testing, potentially indicating greater chromatic sensitivity of SWAP to blue-light filtering. Similarly, Kim et al[23] and Ueda et al[24] reported no significant differences in MD or PSD between clear and yellow-tinted IOLs during FDT. These findings suggest that yellow-tinted IOLs have little to no effect on the PSD values, while the MD results demonstrate variability depending on the testing modality and conditions.

Different trends have been reported in glaucomatous eyes, with only one study addressing this issue. Nilforushan et al[25] investigated the effect of cataract surgery with yellow-tinted IOL implantation on SAP and SWAP outcomes in patients with mild-to-moderate glaucoma. Postoperatively, a significant improvement in SWAP MD values was observed ($p = 0.001$), likely due to the removal of cataract-induced light scattering rather than the chromatic properties of the yellow-tinted IOL itself. Conversely, the PSD values showed no significant changes after surgery, indicating that the variability in the VF sensitivity remained stable This study also found that MD improvement was more pronounced in SWAP than in SAP ($p = 0.03$), reflecting SWAP's sensitivity to early glaucomatous damage, particularly in the koniocellular pathway responsible for blue-yellow light processing.

The stability of the PSD values across studies and the variable effects on MD reported in these investigations provide a useful foundation for interpreting our findings. However, it is critical to acknowledge the inherent differences between internal and external chromatic filtering mechanisms, underscoring the need for further research to delineate the specific effects of external filters, such as KIROS 1–400, on SAP outcomes and their implications for glaucoma diagnosis and management.

The impact of colored filters on SAP testing has been explored in a limited number of studies, mostly outside the context of glaucoma. Notably, a study involving patients with cone dystrophy demonstrated that the application of the CPF®527 filter, which exhibits optical properties comparable to those of the KIROS 1–400 filter, led to an improvement in central VF performance. However, the study did not elaborate on the extent of the observed improvement or the specific methodologies utilized, thereby limiting the interpretability and generalizability of the findings.[26] Additionally, in patients with retinitis pigmentosa and relatively preserved VFs, the application of a red filter resulted in reduced sensitivity, while in patients with severely restricted VFs, only minimal improvement was observed with the use of the filter.[27]

The application of the KIROS 1–400 filter during SAP testing resulted in the reclassification of glaucoma severity in a subset of eyes based on the GHT results, notably reducing the number of eyes categorized as Borderline while maintaining high accuracy for ONL cases. The GHT analysis is designed to detect asymmetries between the superior and inferior hemifields by comparing clusters of test points.[28] When the difference between these hemifields exceeds a certain threshold ($p < 0.01$), the result is categorized as ONL. When the difference is borderline ($p < 0.03$), it is classified as "Borderline". The GHT algorithm detects localized VF losses typical of glaucoma, where asymmetric defects often result from glaucomatous damage.

The KIROS 1–400 filter appears to enhance both the sensitivity and specificity of the glaucoma diagnosis. Improved sensitivity is demonstrated by the reclassification of WNL cases to ONL (four cases) and Borderline (three cases), suggesting improved detection of early or subtle glaucomatous changes.

Figure 1 illustrates a representative case where the filter enhanced sensitivity by accurately identifying a true ONL case in the VF, consistent with the structural glaucomatous damage confirmed through OCT imaging. The enhanced specificity is reflected in the reduction of false-positive classifications. Specifically, ONL cases were reclassified into less severe categories—seven to Borderline and one to WNL. No cases were reclassified from Borderline to ONL.

Figure 2 presents a representative example of an ONL eye (without the KIROS filter) that was reclassified as WNL when the filter was applied. This reclassification aligns with the absence of significant RNFL and ganglion cell complex

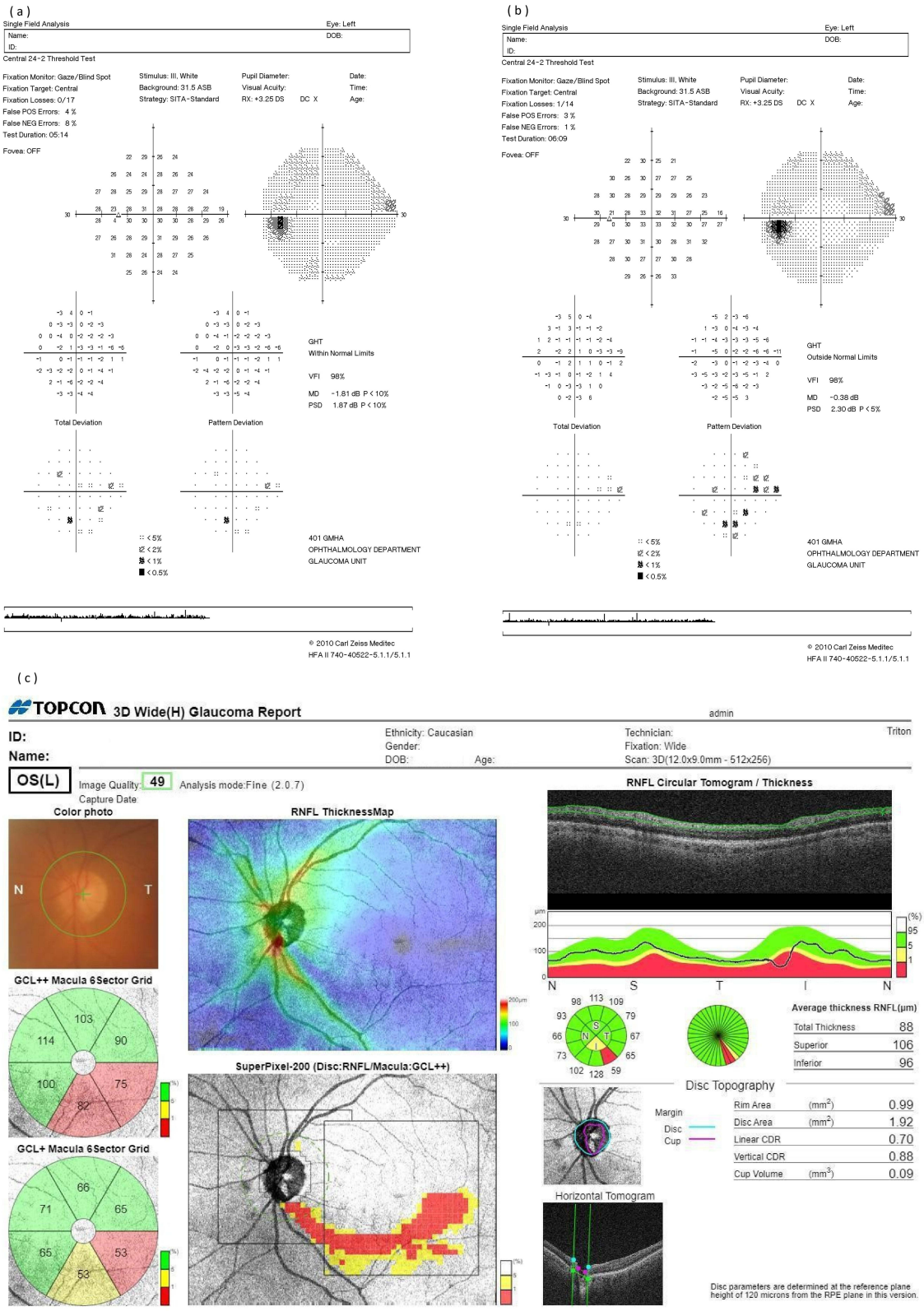

Figure 1 Representative case illustrating the reclassification of (**a**) a Within Normal Limits (WNL) case (without the KIROS filter) to (**b**) Outside Normal Limits (ONL) (with the KIROS filter). (**c**) Additional optic nerve head imaging using Optical Coherence Tomography (OCT) revealed inferior retinal nerve fiber layer (RNFL) and ganglion cell complex (GCC) thinning, which corresponded to the superior nasal step identified in the visual field when the KIROS filter was applied. This case illustrates the filter's ability to enhance sensitivity by detecting true ONL cases in the visual field, consistent with structural glaucomatous damage evident on imaging.

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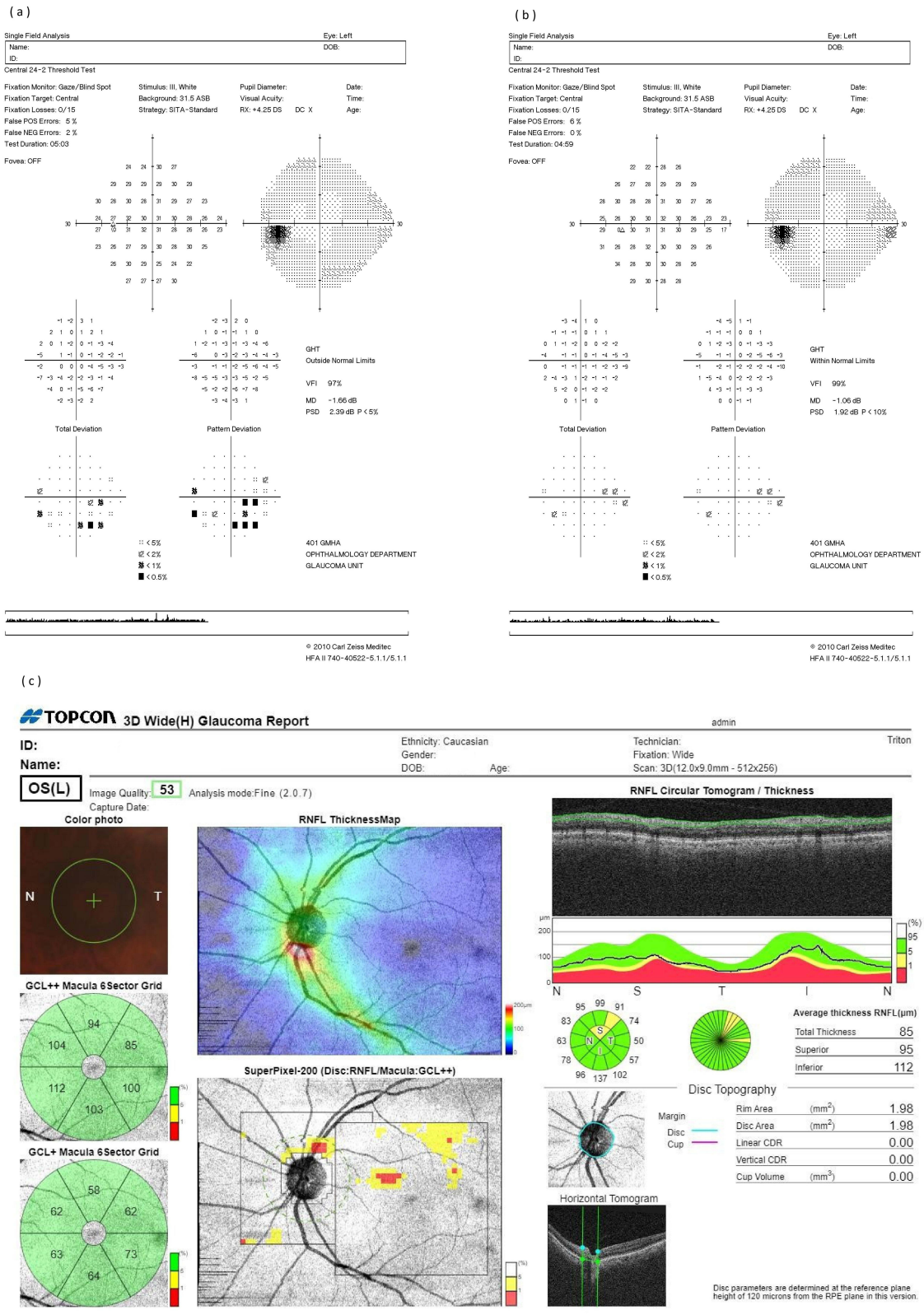

Figure 2 Representative case illustrating the reclassification of (**a**) an Outside Normal Limits (ONL) case (without the KIROS filter) to (**b**) Within Normal Limits (WNL) (with the KIROS filter). (**c**) Optic nerve head imaging using Optical Coherence Tomography (OCT) revealed only borderline thinning of the superior retinal nerve fiber layer (RNFL) and ganglion cell complex (GCC), which is insufficient to explain the VF defect observed without the KIROS filter. This case highlights the filter's ability to reduce false-positive classifications or over-diagnosis, potentially improving diagnostic specificity by minimizing the impact of noise or artifacts.

(GCC) damage, as only borderline thinning was observed on OCT imaging. This likely reflects the ability of the filter to reduce false-positive classifications and overdiagnosis by minimizing noise and artifacts.

While the KIROS 1–400 filter shows significant potential in improving the accuracy of glaucoma diagnoses, its use may need to be supplemented with additional diagnostic modalities to ensure the comprehensive detection of early glaucomatous changes, as illustrated in Figures 1 and 2. The observed reclassifications were likely the result of a complex interaction between the optical properties of the filter and its effects on the physiological mechanisms involved in visual processing.

The retina contains three types of cones: short-wavelength cones (blue-sensitive, 400–440 nm), medium-wavelength cones (green-sensitive, 530–540 nm), and long-wavelength cones (red-sensitive, 560–580 nm).[29] These cones contribute to two primary color mechanisms (blue-yellow and green-red) and one achromatic mechanism (black-white). The blue-yellow mechanism, which is essential for detecting short-wavelength stimuli, can be modulated by filters that absorb blue light, such as the KIROS 1–400 filter.

The absorption of blue light by the KIROS filter suppresses blue cone activity while enhancing the perception of wavelengths in the yellow-to-red spectrum. By blocking wavelengths of up to 400 nm and transmitting light near the eye's peak sensitivity (555 nm), the filter enhances CS and reduces intraocular scatter. This improves the signal-to-noise ratio in perimetric testing, facilitating the detection of significant asymmetries between the superior and inferior hemifields and increasing ONL classifications.

However, the selective suppression of the blue-yellow pathway may impair the detection of subtle defects mediated by the koniocellular pathway, potentially reducing Borderline classifications in favor of WNL. These findings suggest that while the KIROS filter enhances the detection of more pronounced glaucomatous damage (ONL), it may obscure early, subtle VF defects (Borderline) associated with the blue-yellow mechanism.

Our findings align with those of studies on yellow-tinted IOLs used in SWAP, where yellow-tinted IOLs significantly altered GHT classifications. Jang et al[22] demonstrated that yellow-tinted IOLs reduced sensitivity to blue light stimuli, resulting in more ONL classifications and fewer borderline and WNL results. Additionally, during SWAP, the presence of yellow-tinted IOLs was associated with worse MD and PSD than those observed with non-tinted IOLs, highlighting the adverse effects of blue light filtering on SWAP accuracy.

Although the underlying mechanisms differ between SWAP and SAP, the GHT reclassification trends are comparable. In SWAP, yellow-tinted IOLs directly disrupt the blue-yellow pathway, reducing sensitivity to blue stimuli against a yellow background. In SAP, yellow filters, such as Kiros 1–400 primarily enhance the overall CS by absorbing short-wavelength blue light (380–500 nm). This may reduce the ability of the test to detect subtle VF defects, leading to under-detection or misclassification of borderline cases. However, in both scenarios, the increased ONL classification suggests that yellow filters or lenses reduce the noise and improve the detection of more pronounced glaucomatous damage.

The present study also evaluated the impact of the Kiros 1–400 yellow-tinted external filter on CS in patients with early and pre-perimetric glaucoma. Using the PR test, our results indicated a statistically significant improvement in photopic CS in both patient groups ($p < 0.001$ for early glaucoma and $p = 0.01$ for pre-perimetric glaucoma). However, the mean improvement of approximately 0.03 log CS, which is equivalent to less than one letter on the PR chart, is unlikely to be clinically significant and should be interpreted with caution. These findings suggest that while the Kiros filter enhances CS under specific conditions, its practical implications in the early disease stages require further investigation.

Our results partially align with those of previous studies on the impact of yellow-tinted lenses on visual performance. Most studies indicate that CS in eyes with yellow-tinted lenses or IOLs is comparable to or better than that in eyes with non-tinted lenses.[30–33] For example, Yuan et al[31] reported that yellow-tinted blue-light-filtering IOLs (BF-IOLs) improved CS at low to middle spatial frequencies, whereas Mainster et al[34] found no significant benefit. Additionally, Mainster and Turner[35] argued that blue-blocking IOLs do not significantly improve CS in patients with pseudophakia. Their claims were supported by empirical research, clinical observations, and comparative analyses of UV-blocking IOLs, illustrating the limitations of blue-blocking technology in improving visual outcomes. Similarly, Rodriguez-Galietero et al[36] observed comparable CS outcomes in eyes with yellow-tinted and non-tinted IOLs; however, their study was limited to photopic conditions without glare.

Clinical studies examining patients with pseudophakia have also demonstrated no significant differences in CS between eyes implanted with BF-IOLs and those implanted with ultraviolet-blocking IOLs (UVB-IOLs).[36–39] Notably, Kitnarong et al[40] assessed the effects of BF-IOLs and UVB-IOLs in patients with glaucoma undergoing cataract surgery.

Their findings indicated that both IOL types improved the CS postoperatively without significant differences between the groups. These results highlight the general utility of yellow-tinted filters or IOLs in enhancing visual performance under certain conditions, although their specific impact on patients with glaucoma warrants further investigation.

Yellow filters, such as the Kiros 1–400, have been proposed to enhance CS in individuals with glaucoma through two primary mechanisms, which are informed by the Large Cell Loss Theory of glaucoma[41–43] and the Reduced Redundancy Hypothesis.[44,45] First, these filters enhance luminance contrast and mitigate chromatic aberration induced by short-wavelength blue light, thereby improving the functional output of residual magnocellular (M) cells. This enhancement compensates for deficits in motion detection and peripheral vision, which are predominantly mediated by the M pathway.[41–43] Second, consistent with the Reduced Redundancy Hypothesis, yellow filters optimize input to the M pathway while reducing compensatory demands on the parvocellular (P) pathway, which is less effective in processing low-contrast stimuli.[44,45] By selectively filtering blue light and transmitting light near the eye's peak sensitivity, yellow filters stabilize visual input and enhance the residual M pathway function, thereby supporting better CS and peripheral vision.

Strengths and Limitations

One of the key strengths of this study is its innovative approach, addressing a notable gap in glaucoma research by evaluating the impact of the KIROS 1–400 external yellow-tinted filter on visual function in patients with PPG and early glaucoma. Unlike prior studies that focused on intraocular lenses, this research highlights the potential of non-invasive, high visible light transmission filters to enhance specific aspects of visual function. The study employed a robust design, incorporating comprehensive assessments of both CS and VF indices, while ensuring adequate statistical power through predefined parameters and interim sample size calculations. Furthermore, the use of an external filter highlights a non-invasive and cost-effective option for enhancing specific aspects of visual function, offering practical clinical applicability.

However, it is important to acknowledge that interim sample size calculations, while resource-efficient, are inherently influenced by initial results. This limitation, combined with a relatively small sample size, may have limited the ability to identify larger or more clinically meaningful differences, should they exist. This highlights the importance of future studies with larger, pre-determined sample sizes to confirm and expand upon our findings. Secondly, while the KIROS 1–400 filter demonstrated a statistically significant improvement in CS for both patient groups, the observed increase of approximately 0.03 log CS corresponds to a difference of less than one letter on the PR chart. This minimal improvement, though statistically significant, is unlikely to yield clinically meaningful benefits in most real-world scenarios. Nonetheless, the findings highlight the potential of blue light-filtering technologies to improve certain aspects of visual function, though their broader clinical implications require further exploration in larger and more diverse patient populations.

A further limitation is that masking was not possible due to the filter's visible tint. However, this was mitigated by using randomized test order and objective, standardized testing protocols that minimized the potential for observer or participant bias. Given the limited number of predefined outcomes, no correction for multiple comparisons was applied, as the associated risk of type I error was considered low.

Finally, our study relied exclusively on the PR chart to evaluate CS. While effective for photopic CS in well-lit conditions, this approach does not account for scotopic or mesopic CS, essential for a comprehensive assessment of visual performance in glaucoma. Future research employing additional methodologies to assess scotopic and mesopic CS could provide greater insight into the clinical relevance of blue light-filtering technologies and their role in managing visual function in glaucoma. Considering these limitations, this study provides a foundation for further investigation with larger sample sizes to validate and extend these findings, providing greater insight into the long-term clinical utility of such filters in glaucoma management.

Conclusion

Our study provides a novel perspective by examining how the external KIROS 1–400 filter, specifically designed to enhance CS, affects key perimetric indices such as MD, PSD, VFI, and GHT in patients with early glaucoma. These findings contribute to a better understanding of how external filters with high VLT levels can modulate visual performance in glaucoma, particularly for detecting glaucomatous damage and managing the disease.

Clinically, our results confirm a statistically significant but modest improvement in CS, corresponding to a mean gain of less than one letter on the Pelli-Robson chart. While this may not translate into meaningful functional benefit, it suggests a potential role for yellow-tinted filters in enhancing visual comfort under specific conditions. We also highlight the need for caution in interpreting GHT results when such filters are used, especially in patients with early or pre-perimetric glaucoma. Although enhanced detection of advanced defects may assist in identifying severe glaucomatous damage, the potential under-detection of borderline changes could delay early diagnosis or monitoring.

Unlike SWAP, where yellow-tinted IOLs have a more pronounced impact, SAP appears to be less influenced by external, yellow-tinted filters. However, further research is required to determine the long-term clinical implications of yellow filters on VF outcomes, and their relevance in routine early-stage glaucoma care.

Further comparative studies are required to evaluate the long-term effects of external filters relative to IOLs, particularly regarding their clinical utility and impact on VF testing outcomes. Although the external KIROS 1–400 filter demonstrated potential to enhance CS in early and pre-perimetric glaucoma, these preliminary findings should be interpreted with caution. Robust studies with larger cohorts and clinically relevant endpoints are necessary to determine its practical role in glaucoma management.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors have no conflicts of interest in this work.

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