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ARTICLE

Glaucoma

Online circular contrast perimetry performed in glaucoma patients in Sub-Saharan Africa: a multi-centre comparative study in Nigeria

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BACKGROUND/OBJECTIVES: Online circular contrast perimetry (OCCP) provides visual field testing on any computer or tablet, without additional hardware. Its performance has not been evaluated in an African cohort. This study compared the performance of OCCP to standard automated perimetry (SAP) in a cohort of Nigerian patients with glaucoma.

SUBJECTS/METHODS: Across 404 patients (198 males, 206 females), OCCP mean deviation (MD) and pattern standard deviation (PSD) were compared with SAP using paired analyses, Bland–Altman plots, intraclass correlation coefficients (ICC) and Pearson correlation. The correlation between MD and vertical cup-to-disc ratio (VCDR) was assessed using linear regression. Reliability indices, including fixation losses (FL), false positives (FP), and false negatives (FN), were also compared.

RESULTS: Mean OCCP MD was higher than SAP in both eyes ($p < 0.001$). Bland–Altman analysis demonstrated a positive bias toward higher MD values with OCCP (1.09–1.53 dB), while ICCs indicated moderate reliability and correlation with SAP (0.52–0.53). MD showed stronger correlations with VCDR for OCCP than for SAP ($r = -0.41$ to -0.48 vs -0.32 to -0.41), although these differences were not statistically significant. Mean PSD values were similar between devices with minimal bias (-0.10 to -0.16 dB); however, agreement and correlation were poor (ICC 0.39; $r = 0.39$–0.40). Reliability indices (FL, FP, FN) were comparable between OCCP and SAP.

CONCLUSIONS: OCCP demonstrates consistent moderate agreement with SAP for MD, with similar reliability. As a potential screening and surveillance tool, OCCP could be used to substantiate visual field testing in SSA, especially where perimetry availability is limited.

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INTRODUCTION

Sub-Saharan Africa (SSA) has the highest global burden of glaucoma, with a prevalence of 4.4% [1]. By 2040, cases are projected to double to 16.2 million, making it one of the most significant emerging public health challenges [2]. Efforts to address glaucoma in Africa remain difficult, with high rates of undiagnosed disease and poorer prognostic outcomes [3]. Many of these challenges are driven by limited infrastructure and severe resource constraints. There is a marked shortage of ophthalmologists and eye care services, particularly in rural and remote areas [4]. The absence of screening and outreach programs, combined with the largely asymptomatic nature of early disease, contributes to late presentations and poorer outcomes [5]. Clinics are often under-resourced, and subjective clinical assessments may require multiple visits before diagnosis, further delaying care [6, 7]. Knowledge gaps also persist, with some clinicians relying on intraocular pressure alone, overlooking other key features, including in normotensive disease [8]. Unlike cataracts, glaucoma requires lifelong

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management, yet treatment outcomes remain poor due to access barriers, limited resources, and poor adherence, perpetuating a high burden of undiagnosed and undertreated disease [8]. Consequently, glaucoma was not prioritised in the first phase of Vision 2020 in Africa [9, 10]. This underscores the need for improved screening and diagnostic strategies that expand access, support earlier intervention, and remain cost-effective and sustainable within resource-constrained settings [11].

Standard automated perimetry (SAP) remains central to glaucoma diagnosis and monitoring [12]. However, conventional perimeter machines are limited in SSA by poor availability, high cost, and reduced accessibility. They are expensive, non-portable, require trained staff for calibration, and are prone to breakdown with specialised servicing requirements [13]. Clinic-based testing is also stressful, time-consuming, and associated with poorer patient adherence [14, 15]. Longer test durations may reduce threshold sensitivity (visual fatigue), while reliability is further affected by retest variability, learning effects, and patient performance [16–21]. Additionally, perimetry may fail to detect early disease, as substantial ganglion cell loss precedes measurable visual field defects [12, 22, 23]. Overcoming these limitations could substantially improve the accessibility and scalability of glaucoma care.

Portable perimetry technologies have ushered in a new era in glaucoma care [24]. Over the past decade, applications have been developed across multiple platforms, including laptops [25], tablets [26–28], mobile phones [29, 30] and virtual reality headsets [31, 32], with variable performance and uptake. These tools offer several advantages, including reduced need for clinic visits, shorter testing times, improved user experience, access in rural and remote settings, and the potential for home monitoring and more frequent testing in high-risk patients [33]. With clear economic and accessibility benefits, portable perimetry represents a promising approach to expanding glaucoma care in Africa, supporting large-scale screening and ongoing disease monitoring.

Online circular contrast perimetry (OCCP) is a web-based visual field test, originally designed for desktop use and now optimised for laptops and tablets [34–36]. It has been extensively evaluated and validated for glaucoma detection, demonstrating comparable diagnostic sensitivity to SAP and acceptable reliability across international cohorts, including Australia and Vietnam [13, 14, 36–39]. OCCP shows strong immediate retest and intermediate-term repeatability, and can be reliably performed at home without supervision [40, 41]. Patients also report a preference for OCCP over SAP due to its intuitive interface, improved experience, and remote testing capability [14].

OCCP holds promise for expanding visual field testing for both screening and monitoring; however, it has not yet been evaluated in an African cohort, and its performance in this setting remains uncertain. Africa faces unique healthcare challenges, including higher disease burden, limited healthcare resources, and significant barriers to access and long-term management, underscoring the importance of context-specific evaluation. In this environment, OCCP may provide a practical, low-cost solution to support underserved regions and overstretched glaucoma clinics.

MATERIALS/SUBJECTS AND METHODS

Participants

Participants were recruited for this study between September 2024 to November 2024, from ten glaucoma clinics across Nigeria. Participants were patients with glaucoma who attended these clinics for their routine appointments.

Inclusion and exclusion criteria

All participants had provided informed consent before participating. Inclusion criteria were: age 18 years or above, the ability to understand English, glaucoma in both eyes diagnosed by an ophthalmologist, best corrected visual acuity (BCVA) ≤ 0.8 logarithm of the minimum angle of resolution (logMAR), and reliable SAP and OCCP test results. Glaucoma was defined according to the American Academy of Ophthalmology criteria [42]. Additional optic nerve and optical coherence tomography (OCT) features that were deemed consistent with glaucoma included: diffuse or focal narrowing or notching of the optic disc rim, progressive neuroretinal rim thinning accompanied by increased optic disc cupping, and diffuse or localised thinning of the peripapillary retinal nerve fibre layer (RNFL). Additional indicators included optic disc haemorrhages affecting the disc rim, peripapillary RNFL, or lamina cribrosa; asymmetry in the optic disc neuroretinal rim between eyes consistent with neural tissue loss; presence of beta-zone parapapillary atrophy; and RNFL and/or macular thinning on imaging. Patients who did not consent or had other significant ocular pathology that could confound visual field assessments were excluded.

Clinical assessment

Before perimetric testing, each participant received a detailed baseline evaluation that included demographic and socioeconomic information, intraocular pressure (IOP), best-corrected visual acuity (BCVA), refraction, ocular biometry, and OCT imaging of the optic disc and macula. Visual field testing was performed with the OCCP on laptops in designated clinic rooms, and standard automated perimetry (SAP) using perimeter machines. All participants were provided with comprehensive instructions before undergoing perimetric assessments.

SAP

All participants underwent SAP under uniform testing conditions. Most examinations were conducted on the Humphrey Field Analyzer (HFA; Carl Zeiss Meditec, Dublin, CA) using the SITA Standard strategy. Owing to variations in equipment availability across sites, additional devices included Optopol (Optopol, Poland), Henson (Elektron Eye Technology, United Kingdom), and the Light box (Supplementary Table 1). Testing was performed on both eyes, with the fellow eye occluded during each assessment. Both OCCP and SAP were assessed using conventional reliability criteria as defined by Heij-Krakau [43]. Tests were deemed reliable if fixation losses were <20%, false-positive responses were <15%, and false-negative responses were <15%.

OCCP

The OCCP application has been previously described in detail in previous studies, therefore, a concise overview of its key features is provided to contextualise the present study [14, 34]. A summary of its main features is presented in Fig. 1A–E. Briefly, OCCP is an online platform that evaluates 52 test loci within 24 degrees of eccentricity, with a Python-based server backend and a JavaScript frontend. During testing, participants maintain fixation on a central stimulus (a rotating star subtending 3.5 degrees of visual angle) and respond via mouse click when peripheral targets appear (Fig. 1A, B). To correspond with different areas of the visual field, the fixation target is repositioned sequentially across the four screen quadrants. The stimuli consist of alternating light and dark rings, designed with spatial and temporal characteristics comparable to those used in Pulsar perimetry (Haag-Streit International) [44]. However, targets are comparatively smaller in size (3.5 vs 5 degrees of visual angle), which allows for finer, spatial mapping of visual field loss [44, 45]. Like SAP, targets are spaced six degrees apart, with magnification toward the periphery to simulate the Ganzfield bowl of the SAP perimeter (Fig. 1C).

Target presentations are 60 milliseconds over three on/off cycles for a total of 360 milliseconds (Fig. 1C). Targets contain temporal counter-phase flickering at 8.3 Herz (Hz) and sinusoidal

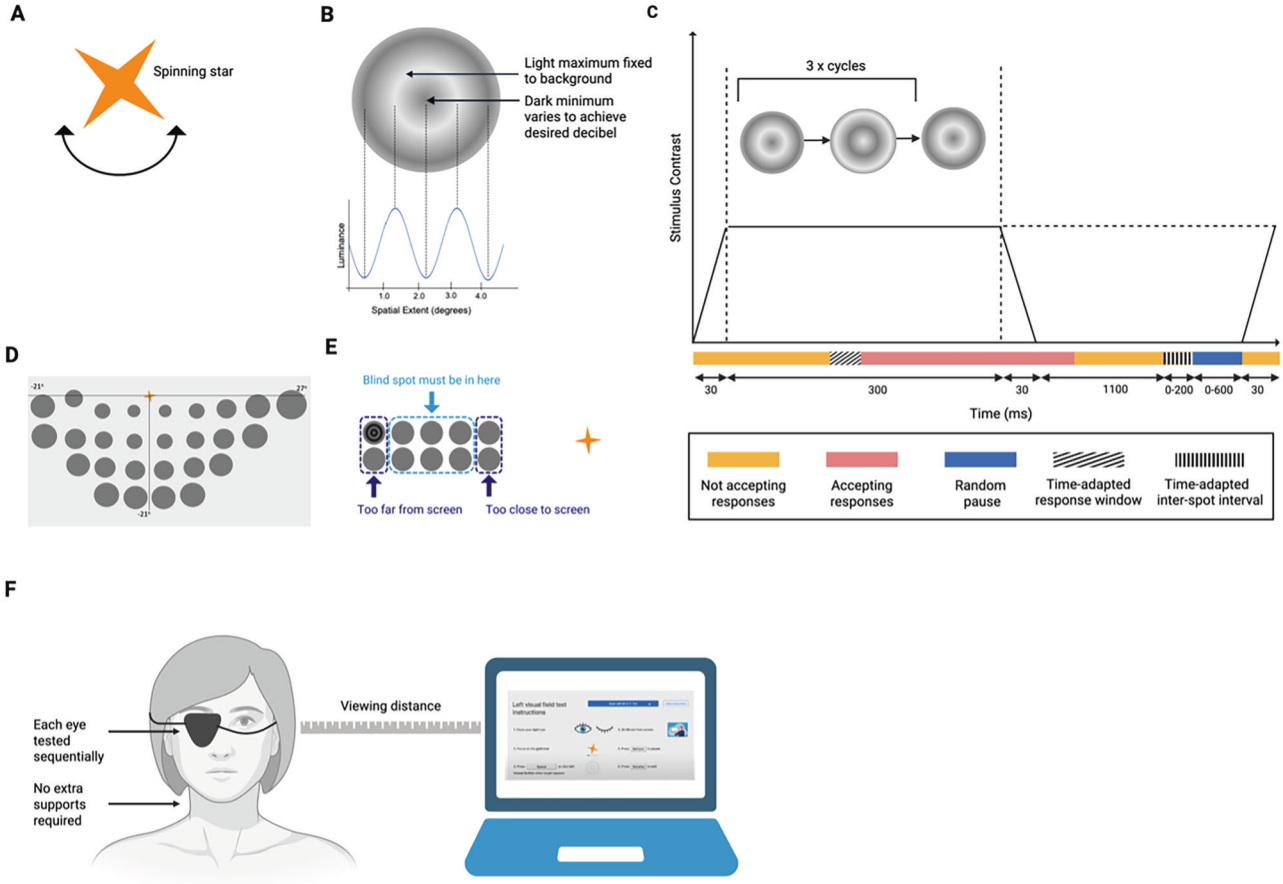

Fig. 1 Online circular contrast perimetry test features. A Spinning fixation target. **B** Concentric, flickering targets used for visual field assessment. **C** Temporal profile of target presentations: targets appear for three on/off cycles over 360 degrees, with graded onset/offset over 50 milliseconds. There are random pauses to prevent rhythmic responses. **D** Spatial scaling of stimuli, with larger targets in the peripheral field and smaller targets centrally to maintain angular resolution. **E** Blind spot localisation procedure, using targeted testing of adjacent regions to confirm position. **F** Standardisation of viewing distance based on monitor characteristics and blind spot mapping to ensure consistent visual angle across devices. Figure adapted from Meyerov et al., and Alawa et al. [14, 30].

contrast with a spatial frequency of 0.55 cycles/degree. This is comparatively slower than traditional frequency doubling perimetry (FDP, Welch Allyn and Carl Zeiss Meditec), where targets exhibit a spatial frequency of 0.5 cycles/degree at a rate of 18 Hz [46]. Contrast is ramped up and down over 30 milliseconds, at the beginning and end of target presentations to prevent temporal transients and unintended saccadic movements [46, 47]. In FDP, background luminance is the average of the light and dark bands [48]. In OCCP, light bands are the same colour as the background screen (light grey), whereas the dark bands are varied to achieve the desired contrast, similar to a luminance pedestal flicker. This allows for coding of fewer grayscale colours, which helps to minimise variability between display parameters across different screens [35, 36]. In essence, OCCP's test parameters, including stimulus size, spatial frequency, background luminance, and flicker rate, have been optimised to enhance consistency across different computer displays, gamma functions, and testing environments [41]. These settings were developed through review of the existing literature, pilot testing, and iterative refinement informed by prior OCCP studies [35, 41]. The application also incorporates an internal calibration process based on the user's early test responses and, where available, data from previous tests performed either on the same device or by the same participant on alternative devices [41].

OCCP utilises three mechanisms to maintain correct viewing distance without head supports. The application calculates the desired viewing distance based on the pixels of the device, ensuring that targets are presented in the correct locations and the viewing angle is kept consistent. At the test's outset, the user's blind spot is mapped (Fig. 1E). From estimating its position at 15 degrees temporal and 0.5 degrees inferior to fixation, small areas (0.5 degrees) around this region are tested on a 4×10-degree grid. Users are instructed to manoeuvre based on the location of the blind spot. User position is generally set at 40–45 cm from the screen, although this varies with different monitor sizes to achieve a consistent viewing angle (Fig. 1F). The user is then continuously monitored by the computer's webcam, tracking head position with a refresh rate of 1 s. The application incorporates a machine-learning program with a facial detection (not recognition) software. Any movements beyond 15% in four planes trigger the test to pause, and the user is verbally instructed to correct their position. In combination, these mechanisms maintain head position with an error rate below 1% [49].

Reliability. OCCP tests adhered to the same reliability criteria as for SAP [43]. Fixation losses are assessed by intermittently presenting a smaller (0.5 degree) high contrast target in the user's blind spot. An acceptable time window is defined for responses, and clicks outside this window are recorded as false positives. Failure to respond to higher-intensity stimuli at previously detected locations was recorded as a false negative. The application also incorporates random time delays to prevent rhythmic clicking (Fig. 1C).

Testing procedure. All desktop monitors and laptops were equipped with webcams and reliable internet access, which was checked before testing. Efforts were made at all sites to standardise testing conditions, including control of background noise and ambient lighting. Before testing, participants received standardised information sheets, and OCCP provided additional built-in verbal and visual instructions to guide users through setup and test procedures. Participants were positioned at the correct viewing distance, automatically determined by the application based on screen size and the user's blind spot. Trained staff were present throughout testing to supervise participants..

Statistics

Data were analysed using GraphPad Prism 9.0 (GraphPad Software Inc., San Diego, CA) and Real Statistics in Excel 2016 (Microsoft 365). Mean deviation (MD) was the primary outcome utilised for assessing perimetric agreement and correlation. It is a validated perimetric variable used extensively for such comparisons [33, 50]. MD was also correlated with the vertical cup-to-disc ratio (VCDR) and compared to that of SAP [51]. Secondary outcomes included pattern standard deviation (PSD) and reliability parameters including fixation loss (FL), false positive (FP) and false negative (FN) responses. To compare OCCP and SAP across different glaucoma severities, participants were subdivided by SAP MD deficit into mild (MD > –6.0 dB), moderate (MD –12.0 to –6.0 dB) and severe (MD < –12.0 dB) disease groups [52]. Because of the inter-eye correlation effect, analysing both eyes together can violate assumptions of independence and bias statistical comparisons [53]. Therefore, right and left eyes were analysed separately, which is a validated statistical approach [53]. Comparison of means was performed using *t*-tests or analysis of variance (ANOVA) for parametric data, or Mann–Whitney U analysis of ranks, with statistical significance set at $P < 0.05$. Agreement between the perimetric indices was evaluated by determining the Bland–Altman plots to estimate bias and the 95% limits of agreement (LoA). Linear regression and Pearson's correlation coefficients were used to estimate the degree of correlation. Dependent correlations were compared using Williams' test. Inter-test reliability was assessed with intraclass correlation coefficients (ICCs) [54]. A priori sample size and power calculations were performed for paired comparison of MD between OCCP and SAP. Assuming a two-sided α of 0.05 and 90% power, and based on the observed effect sizes for the right (0.15) and left (0.19) eyes, 304–357 eyes would be required. As 404 participants were included, with right and left eyes analysed separately, the study was adequately powered for the primary paired comparison of MD between OCCP and SAP.

RESULTS

404 patients (198 males, 206 females) were included in the final analysis. Supplementary Table 1 presents the baseline demographic and clinical data for included participants. Twenty-seven patients were excluded because of missing or unreliable data.

Global perimetric indices

Table 1 presents agreement and correlation for right and left eyes for OCCP and SAP. Bland–Altman plots and linear regression curves for MD and PSD are shown in Fig. 2A–H. OCCP mean MD was higher than SAP for both right (−7.37 vs −8.46, $p = 0.0006$) and left eyes (−6.89 vs −8.42, $p = 0.0002$), with bias differences of 1.09 (LoA −13.27 to 15.45, Fig. 2A) and 1.53 (LoA −12.61 to 15.66, Fig. 2B), respectively. Linear regression analysis showed a statistically significant relationship between OCCP and SAP MD ($p < 0.0001$). Pearson correlation coefficients indicated moderate

Table 1. OCCP versus SAP for MD, PSD and VCDR correlation.

	Right eyes			Left eyes		
	OCCP	**SAP**	**Significance**	**OCCP**	**SAP**	**Significance**
MD (dB)	−7.37 ± 7.52	−8.46 ± 7.55	0.0006	−6.89 ± 7.44	−8.42 ± 7.59	0.0002
MD > −6	−4.61 ± 5.92	−4.52 ± 5.53	0.11	−4.52 ± 5.52	−2.95 ± 1.67	0.22
MD −12 to −6	−6.04 ± 5.56	−8.76 ± 1.80	<0.0001	−5.32 ± 5.90	−8.40 ± 1.68	<0.0001
MD < −12	−14.08 ± 7.69	−19.48 ± 4.80	<0.0001	−13.15 ± 8.49	−19.93 ± 4.82	<0.0001
PSD (dB)	3.91 ± 2.80	4.02 ± 2.53	0.61	3.69 ± 2.99	3.85 ± 2.46	0.21
MD > −6	2.82 ± 2.17	3.12 ± 1.78	0.09	2.85 ± 2.07	2.82 ± 1.42	0.78
MD −12 to −6	4.12 ± 2.36	4.23 ± 2.41	0.94	3.64 ± 2.91	4.68 ± 2.38	0.007
MD < −12	6.29 ± 2.85	6.01 ± 2.30	0.43	5.58 ± 3.23	5.77 ± 2.94	0.72
MD/VCDR correlation	−0.41 (−0.49, −0.32)	−0.32 (−0.42, −0.23)	0.10	−0.48 (−0.55, −0.39)	−0.41 (−0.49, −0.32)	0.57
	Bland–Altman Bias (dB)	**Bland–Altman 95% LoA (dB)**	**ICC (95% CI)**	**Bland–Altman Bias (dB)**	**Bland–Altman 95% LoA (dB)**	**ICC (95% CI)**
MD (dB)	1.09	−13.27, 15.45	0.52 (0.42, 0.61)	1.53	−12.61, 15.66	0.53 (0.43, 0.61)
PSD (dB)	−0.10	−5.88, 5.67	0.39 (0.30, 0.49)	−0.16	−5.93, 5.60	0.39 (0.28, 0.49)

Results are expressed as mean ± standard deviation unless otherwise specified.

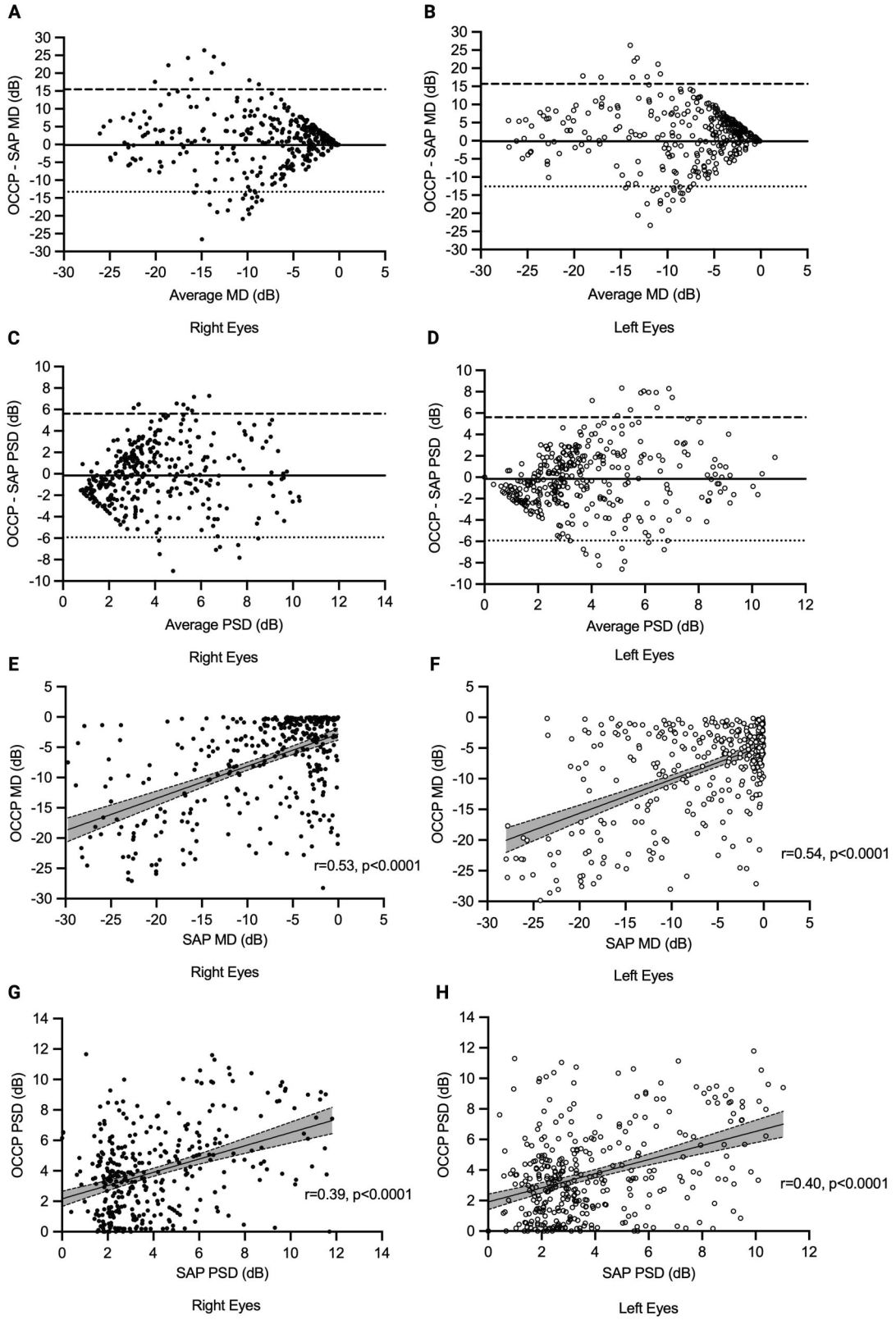

Fig. 2 Agreement and correlation between OCCP and SAP. Bland–Altman plots (**A**–**D**) and linear regression analyses (**E**–**H**) comparing mean deviation (MD) and pattern standard deviation (PSD) between OCCP and SAP in right and left eyes. Bland–Altman plots display the mean difference (bias) between tests with 95% limits of agreement shown by dashed lines. Dotted lines and the shaded region represent the 95% confidence intervals for the regression curves (solid line). Right eyes are shown as black circles and left eyes as open circles.

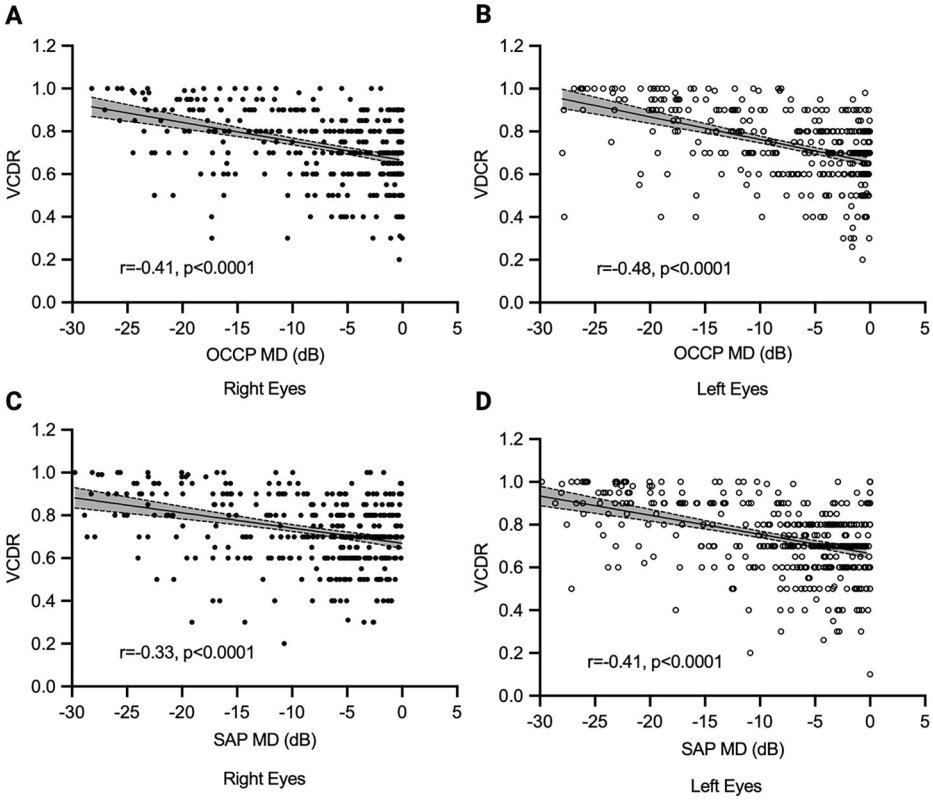

Fig. 3 Linear regression analyses of mean deviation (MD) and vertical cup-to-disc ratio (VCDR). MD vs VCDR for OCCP (**A**, **B**) and SAP (**C**, **D**). Solid lines represent regression fits with 95% confidence intervals shown in shaded regions. Right eyes are shown as black circles and left eyes as open circles.

correlation (0.53, 0.54, Fig. 2E, F), and ICCs demonstrated moderate reliability (0.52, 0.53, Table 1).

When stratified by disease severity, OCCP mean MD was similar to SAP in eyes with mild visual field loss (MD > −6 dB), with no statistically significant differences observed in right eyes (−4.61 vs −4.52, $p = 0.11$) or left eyes (−4.52 vs −2.95, $p = 0.22$, Table 1). However, OCCP mean MD was higher than SAP in eyes with moderate visual field loss (MD −12 to −6 dB) for both right (−6.04 vs −8.76, $p < 0.0001$) and left eyes (−5.32 vs −8.40, $p < 0.0001$). Similar findings were observed in advanced disease (MD < −12 dB), where OCCP demonstrated higher MD values than SAP in right (−14.08 vs −19.48, $p < 0.0001$) and left eyes (−13.15 vs −19.93, $p < 0.0001$).

OCCP mean PSD was similar to SAP across both right (3.91 vs 4.02, $p = 0.61$) and left eyes (3.69 vs 3.85, $p = 0.21$, Table 1). Bias differences in PSD were −0.16 (LoA −5.88 to 5.67, Fig. 2C) and −0.10 (LoA −5.93 to 5.60, Fig. 2D) in both right and left eyes, respectively.

Linear regression analysis showed a statistically significant association between OCCP and SAP PSD values in both eyes ($p < 0.0001$). Pearson correlation coefficients indicated poor correlation (0.39, 0.40, Fig. 2G, H), and ICCs demonstrated poor reliability (0.39, 0.39, Table 1).

In eyes with mild visual field loss, PSD values were similar between OCCP and SAP for right (2.82 vs 3.12, $p = 0.09$) and left eyes (2.85 vs 2.82, $p = 0.78$). Similarly, in advanced disease, PSD values remained comparable between OCCP and SAP in right (6.29 vs 6.01, $p = 0.43$) and left eyes (5.58 vs 5.77, $p = 0.72$). A statistically significant difference was observed only in left eyes with moderate visual field loss, where OCCP mean PSD was lower than SAP (3.64 vs 4.68, $p = 0.007$), while right eyes remained similar (4.12 vs 4.23, $p = 0.94$).

MD vs VCDR

MD showed a moderate negative correlation with VCDR in both OCCP and SAP across both right and left eyes (Fig. 3). Shown in Table 1, this relationship appeared stronger for OCCP compared with SAP in both right eyes (−0.48 vs −0.41, $p = 0.10$) and left eyes (−0.46 vs −0.32, $p = 0.57$), however, these differences were not statistically significant.

Reliability

Figure 4 compares the reliability indices between OCCP and SAP, showing statistically insignificant differences in FL (2.54 vs 1.80, $p = 0.90$), FP (1.31 vs 1.37, $p = 0.90$) and FN responses (8.45 vs 7.23, $p = 0.17$).

DISCUSSION

In SSA, where service provision and infrastructure remain limited, a significant proportion of individuals with glaucoma remain undiagnosed, with no access to perimetry testing [55]. To date, few studies have explored the potential of portable perimetry in African populations [11, 28]. OCCP is a scalable and accessible solution that can potentially be used to strengthen tertiary services, support community-based screening, and facilitate home testing.

This is the first study evaluating OCCP in an SSA glaucoma cohort. OCCP produced higher MD scores compared with SAP (Table 1), reflecting a bias difference between 1.0 and 1.5 dB. While this aligns with our previous cohort studies of OCCP and suggests relative consistency across settings and populations, this study reported wider limits of agreement, particularly for MD, which is suggestive of substantial inter-device variability [40]. Furthermore, both the ICCs and Pearson correlation values for MD

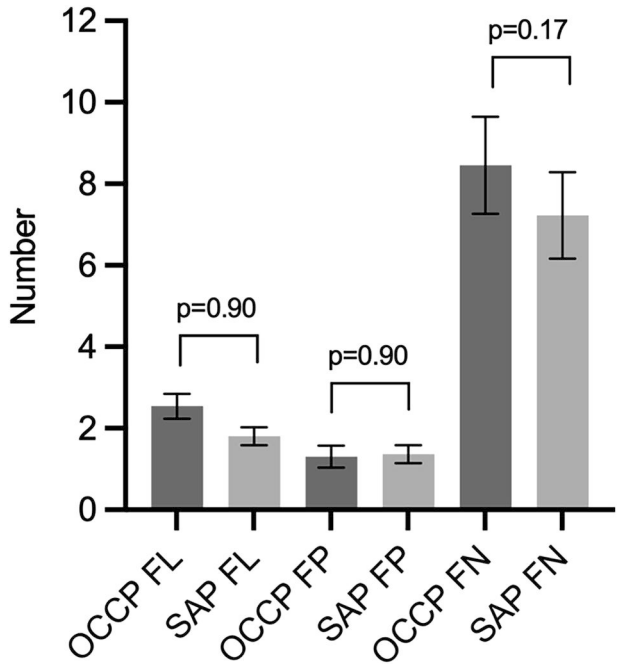

Fig. 4 Comparison of reliability indices between OCCP and SAP, including fixation losses (FL), false positives (FP), and false negatives (FN).

were moderate (ICC = 0.52, 0.53; r = 0.53, 0.54), and agreement for PSD was poor. In other cohorts in which SAP was compared to OCCP, ICCs have often exceeded 0.80 and with correlation coefficients above 0.90 [35, 40]. Several factors have likely contributed to these findings. Across multiple centres, it was often difficult to standardise test conditions, which may have increased measurement variability. Many patients in this cohort had advanced glaucoma, where perimetric measurements are subject to floor effects and increased test–retest variability, which can reduce the reliability and comparability of global indices [16, 56]. Factors that are more prevalent in SSA may further contribute to lower performance and reliability in perimetric testing. These include limited or absent prior exposure to visual field testing, which may affect task comprehension and test execution [57]. This likely introduced additional variability and reflects recognised effects of perimetric inexperience on performance [19–21]. Other contributors include variations in health literacy and familiarity with technology, which can affect the ability to understand instructions or interact effectively with computerised perimetry devices, and the higher prevalence of co-existing ocular comorbidities, such as cataract or uncorrected refractive error, which can degrade test reliability and sensitivity [1, 9, 58, 59]. Such factors can lead to increased variability and bias in visual field measurements compared with populations in high-resource settings. The investigators of the Melbourne Rapid Fields (MRF) tablet-based application noted similar challenges in their study of a local Ghanaian cohort [11]. They reported a bias difference MD of ~3.3 dB and wide limits of agreement, indicating considerable inter-device and inter-test variability [11]. Together, our studies reflect the challenges observed more broadly in African cohorts, where test performance may be affected by both patient-related factors and operational constraints, including limited access to trained personnel, inconsistent testing environments, and equipment availability [1, 4]. The demographic and clinical factors that underpin the difficulties in facilitating visual field testing in SSA emphasise the need for strategies to optimise visual field assessment in the region.

Disease severity appeared to influence agreement between OCCP and SAP. When stratified by severity, OCCP and SAP demonstrated comparable MD measurements in eyes with milder visual field loss, whereas increasing divergence was observed in moderate and advanced disease. In eyes with MD between −12 and −6 dB, OCCP demonstrated higher MD values than SAP by 2.7–3.1 dB, increasing to 5.4–6.8 dB in eyes with MD worse than −12 dB. In contrast, PSD measurements remained broadly comparable across disease severities, with only a single significant difference identified in left eyes with moderate visual field loss. These findings suggest that OCCP and SAP may demonstrate closer agreement in earlier disease, while variability increases with worsening glaucoma severity. Increased variability in advanced glaucoma likely reflects established perimetric behaviour, in which reduced dynamic range, floor effects, and greater localised fluctuations contribute to reduced measurement consistency [16, 56]. Importantly, despite these differences, OCCP continued to demonstrate moderate agreement with SAP across the spectrum of disease severity, supporting its potential utility as an adjunctive visual field assessment tool in resource-limited settings.

In evaluating MD and VCDR, there was a moderate negative correlation that was stronger for OCCP than SAP, although this was not statistically significant (Fig. 3). These findings suggest that progressive optic nerve cupping was associated with worsening visual field loss. Although VCDR may help predict the development of glaucoma, it has been shown to correlate poorly with MD in glaucoma patients [51]. VCDR also has appreciable ceiling and floor effects; approaching 0 or 1, it becomes increasingly difficult to detect meaningful changes in MD. Therefore, there may be a limited capacity to detect early or advanced glaucoma and disease progression [51].

Several factors may account for the observed differences in performance between OCCP and SAP. OCCP employs flickering contrast targets, whereas SAP uses conventional white-on-white stimuli [59]. Unlike SAP, OCCP does not require a chin rest, so variations in head position or posture may influence test results. To mitigate this, OCCP incorporates facial detection software that monitors subtle head movements and fixation, prompting users to adjust their position when necessary. Previous studies have demonstrated that OCCP provides reliable results, even in unsupervised testing conditions [13, 41, 60]. Results from this cohort demonstrate statistically equivocal reliability between OCCP and SAP (Fig. 4). Variations in screen brightness, size and contrast may also lead to performance discrepancies, however, OCCP has been designed to maintain consistency across different screens and devices [35, 36, 61]. Finally, there may have been inter-centre variability in performance; however, all participating sites followed a prescribed standardised testing protocol for both OCCP and SAP assessments.

Using OCCP for glaucoma screening could potentially reduce the rate of undiagnosed disease and late presentations in SSA. However, large-scale screening demands substantial infrastructure, resources, and personnel, and current evidence has failed to support population-wide glaucoma screening as cost-effective [62, 63]. Instead, targeted programs aimed at high-risk groups, including those of African descent, may be more effective [62, 63]. In Nigeria, outreach screening has proven useful for early glaucoma detection [62]. Due to its strong sensitivity in detecting disease, OCCP could potentially serve as an adjunctive screening tool in primary care and tertiary clinics, but protocol optimisation may be required to convert formal 24-2 perimetry to a glaucoma screening tool. While perimetry alone might not be ideal for screening, the advantage of OCCP is that it relies on readily available equipment. Further research is required to evaluate its efficacy in population screening. Having demonstrated favourable repeatability over time, OCCP could also be utilised to monitor disease and allow for more frequent reviews of high-risk patients [40]. The rise of telemedicine since COVID-19 has significantly transformed chronic disease management, giving rise to

teleglaucoma, in which trained staff conduct assessments and transmit the results to specialists [64–67]. Due to its minimal hardware requirements, OCCP is potentially well-suited for telehealth applications via primary care services, including medical practices and pharmacies, as well as for home monitoring [67].

By including participants from multiple centres, the study's findings demonstrate strong external validity. It compared global perimetric indices, which are validated performance indicators. Patients with different levels of disease severity were included, enabling for assessment from across the glaucoma spectrum. However, there were limitations. Both SAP and OCCP were performed during the same visit under controlled clinical conditions; however, the order of testing was not randomised or standardised and varied between centres according to workflow and equipment availability. Similarly, the interval between tests was not standardised, and some participants may therefore have experienced greater visual fatigue than others. While these factors may have influenced perimetric performance and represent limitations of the study, they also reflect real-world clinical conditions, where patients commonly undergo perimetry while fatigued, distracted, or following prolonged clinic visits. Additionally, manual transcription led to missing data and errors, and most patients lacked OCT results. Important test parameters, such as VFI and test duration, were not recorded, although OCCP has previously demonstrated comparable results with SAP for these parameters [14]. Whilst efforts were made to standardise testing conditions across sites, complete standardisation of computers and screen sizes was neither feasible nor intentionally enforced, owing to the variability in available equipment between centres. Importantly, this represents a strength of the study, as it reflects the real-world implementation conditions encountered across resource-constrained settings in SSA, where device heterogeneity is unavoidable. Unlike many portable perimetry platforms that require dedicated hardware or fixed display specifications, OCCP was specifically designed to provide consistent perimetric measurements across a wide range of commonly available computers and monitors. The application incorporates automated calibration of viewing distance, stimulus scaling, and screen parameters to preserve consistent visual angles and stimulus presentation across devices, and has previously demonstrated stable performance across different monitor and screen configurations [35, 36]. This flexibility is a key advantage of OCCP in the African setting, where access to uniform hardware is limited and scalability depends on compatibility with existing infrastructure. As only glaucoma patients were included, the diagnostic capabilities of OCCP for other diseases could not be evaluated in this study; however, these capabilities have been demonstrated in other cohorts [13, 14]. Results may not be fully generalisable to all African populations, as demographics, socioeconomic conditions, and disease patterns can vary; however, given that many SSA settings share broadly similar socioeconomic contexts and population characteristics, the findings may still offer meaningful regional insight. Future studies evaluating specific subpopulations may help further elucidate the influence of age, disease severity, and comorbidities on perimetric performance and agreement. The inclusion of different perimetric devices (other than HFA machines) likely introduced heterogeneity due to differences in stimulus presentation, thresholding strategies, and testing algorithms. However, this reflects real-world clinical conditions in SSA, where access to perimetry is limited and unevenly distributed. This pragmatic approach enhanced recruitment feasibility and external validity, capturing a representative spectrum of patients across resource-constrained settings. Additionally, although small population-level differences in OCCP performance have previously been observed between East Asian and Caucasian cohorts, OCCP incorporates population-specific normative databases, including African normative data, to improve accuracy and applicability across different ethnic groups [37–39]. A formal cost-effectiveness analysis was not undertaken in this study and remains an important area for future research to evaluate the economic implications of implementing OCCP at scale in resource-limited settings. Finally, patient-reported outcome measures (PROMs) were not utilised in this study to evaluate the patient experience. However, user feedback comparing OCCP to SAP has been consistently positive in other regions [14, 38]. Future longitudinal studies are warranted to evaluate OCCP performance over time in larger and more diverse cohorts, including assessment of disease progression and PROMs, building on prior work demonstrating its repeatability, reliability, and patient satisfaction.

Important logistical challenges also remain [36]. Reliable internet access is necessary; however, much of SSA still lacks adequate connectivity and power, despite recent improvements from submarine cable infrastructure, and the potential of mobile-internet [68]. Devices with webcams are also required, yet fewer than 10% of households own a computer [69]. Although the interface is user-friendly, basic staff training is essential to ensure proper test administration. In addition, secure systems for data storage and privacy protection must be established. Clinician acceptance and adoption may further require adjustments to existing clinical workflows. Despite these barriers, OCCP's advantages, including portability, minimal hardware requirements and proven reliability, position it as a promising supplementary tool for glaucoma care in Africa.

In summary, OCCP demonstrates acceptable agreement and consistency with SAP, particularly for MD. In SSA, where large segments of the population lack access to eye care, there is a substantial opportunity to expand testing and improve service provision. Our findings suggest that OCCP can be used to facilitate visual field testing, likely integrated within existing care pathways. Further studies are warranted to evaluate its screening capabilities in this population, as well as its test–retest reliability and long-term repeatability. Nonetheless, the present findings suggest that OCCP holds considerable potential to support earlier detection and ongoing surveillance of glaucoma.

SUMMARY

What was known before:

- OCCP provides reliable performance in detecting and monitoring glaucoma in Australian and Asian cohorts.

What this study adds:

- This study provides a performance of OCCP in a Sub-Saharan African cohort.

DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

OO coordinated the study in Nigeria and oversaw patient recruitment, data collection, manuscript writing, editing, and preparation for submission. JM contributed to data collection, performed data preparation and statistical analysis, and co-wrote the manuscript, oversaw the editing, and submission preparation. DB coordinated the study in Nigeria and supervised patient recruitment, data collection, manuscript writing, editing, and preparation for submission. TFS assisted with clinical data acquisition and contributed to manuscript editing. ACO supported patient assessment and participated in manuscript editing. ASK contributed to patient enrolment, data collection and assisted with reviewing and improving the manuscript. KOA aided in gathering clinical information and contributed to editing the manuscript. CO was involved in patient evaluation and assisted in clarifying and refining the manuscript. AI contributed to data collection and provided critical feedback on the manuscript. BA assisted with clinical data gathering and manuscript revision. ME contributed to patient data acquisition and supported improvements during manuscript editing. AE assisted with compiling clinical information and participated in manuscript refinement. EAA contributed to patient recruitment and offered feedback during manuscript editing. NJU assisted with data gathering and contributed to critical manuscript review. OJH was involved in collecting patient information and refining the manuscript. AEV contributed to clinical data acquisition and assisted with manuscript improvements. FG supported patient data collection and participated in manuscript editing. FL contributed to data acquisition and assisted with reviewing the manuscript. SS coordinated the study in Australia and supervised patient recruitment, data collection, manuscript writing, editing, and preparation for submission.

COMPETING INTERESTS

SS is a director of Eyeonic Pty Ltd, which owns patent WO2021051162A1 regarding online circular contrast perimetry. The remaining authors have nothing to disclose.

ADDITIONAL INFORMATION

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