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Systematic Review

Functional mapping of the central retina: a PRISMA-guided systematic review comparing microperimetry and standard automated perimetry

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ABSTRACT

Microperimetry (MP), also referred to as fundus-controlled perimetry, enables retinal sensitivity (RS) assessment with real-time eye tracking and direct fundus visualisation. Standard automated perimetry (SAP), commonly performed using the Humphrey field analyser (HFA), remains the clinical standard for visual field evaluation. A systematic literature search of PubMed, Scopus, and Web of Science was conducted to identify adult human studies directly comparing MP (MP-1, MAIA, MP-3) with SAP. Inclusion criteria comprised within-subject comparative designs, quantitative RS outcomes, and peer-reviewed English-language publications. Data extracted included RS measures, fixation stability indices, structure, function correlations with optical coherence tomography (OCT), reproducibility metrics, and clinical applicability. Study selection and synthesis followed PRISMA guidelines. Due to methodological heterogeneity, a narrative comparative synthesis was performed. Comparative evidence across glaucoma, diabetic macular oedema, (DME) retinitis pigmentosa, and other macular disorders demonstrated good agreement between MP and SAP for central visual field sensitivity. MP consistently provided superior fixation control, improved test-retest reliability, and closer spatial correlation with OCT-derived structural parameters. In macular-predominant or early central disease, MP is frequently identified with localised functional deficits not evident on SAP. Conversely, SAP remained superior for peripheral visual field assessment and global disease staging. MP offers a precise and reproducible assessment of central retinal function, particularly valuable in macular disease and central glaucomatous damage. SAP remains indispensable for peripheral field evaluation. An integrated use of MP and SAP provides the most comprehensive strategy for clinical assessment and longitudinal monitoring.

Keywords: Microperimetry, Standard automated perimetry, MP-1, MAIA, MP-3, Optical coherence tomography, Age-related macular degeneration, Diabetic macular oedema

INTRODUCTION

Albrecht von Graefe, in 1856, introduced perimetry for the quantitative evaluation of visual field, with limitations of accurate evaluation of macular area function in a diseased person due to instability/extrafoveal fixation.[1-9]

MP, also known as fundus-controlled or macular perimetry, is widely used to assess functional impairment in retinal macular disorders such as age-related macular degeneration (AMD), DME, and various macular dystrophies. It is also an important tool in low-vision rehabilitation, particularly for evaluating eccentric fixation and identifying preferred retinal loci (PRL). By combining conventional perimetry with real-time retinal imaging and fixation tracking, MP enables precise point-to-point mapping of visual stimuli onto corresponding retinal locations, allowing accurate correlation between functional sensitivity and structural changes. These measurements have become increasingly important in patients with retinal disease due to the growing number of pharmacological and surgical interventions (Table 1).

Table 1: Comparative table: MP vs. conventional perimetry.

Features	MP	Conventional perimetry
Primary function	Integrates retinal imaging with functional assessment, enabling detailed evaluation of central visual sensitivity through precisely localised light stimuli over the fundus.	Assesses the visual field by determining RS to standardised light stimuli presented within a dome-shaped projection surface.
Retinal imaging	Equipped with real-time fundus imaging, allowing simultaneous structural-functional correlation.	Lacks integrated fundus visualisation; stimuli are projected onto an external bowl perimeter without direct mapping to retinal structures.
Eye-tracking	Utilises a continuous eye-tracking mechanism to correct for retinal shifts and maintain stimulus localisation despite fixation instability.	Does not incorporate eye-tracking; it relies on patient's ability to maintain fixation during examination.
Fixation assessment	Provides quantitative fixation analysis, including preferred retinal locus (PRL) mapping and stability metrics such as the Bivariate Contour Ellipse Area (BCEA). Performs accurately even though with unstable fixation.	Less reliable in cases of unstable or eccentric fixation, as fixation monitoring is limited and less sensitive.
Structural correlation	Results can be directly co-registered onto retinal landmarks, enabling precise correlation between functional deficits and anatomical abnormalities.	Provides only functional output; structural correlation must be inferred through separate imaging modalities.
Typical clinical use	Optimally suited for macular and central retinal diseases, including AMD, DME, and Stargardt disease; also valuable for PRL assessment in low-vision rehabilitation.	Considered gold standard for evaluating global and peripheral visual field defects, especially in glaucoma, optic neuropathies, and neuro-ophthalmic disorders.

METHODS

Review conducted and reported in accordance with PRISMA 2020 guidelines. Total of 246 records were identified through database searching. After removal of duplicates and screening for eligibility, 55 full-text articles were assessed.

Of these, 46 studies were included in qualitative synthesis, and 12 further eligible for quantitative analysis (Figure 1, PRISMA flow diagram).

Pre-2015 studies were cited solely for historical context and are excluded from quantitative synthesis (Figure 2 and Table 2).

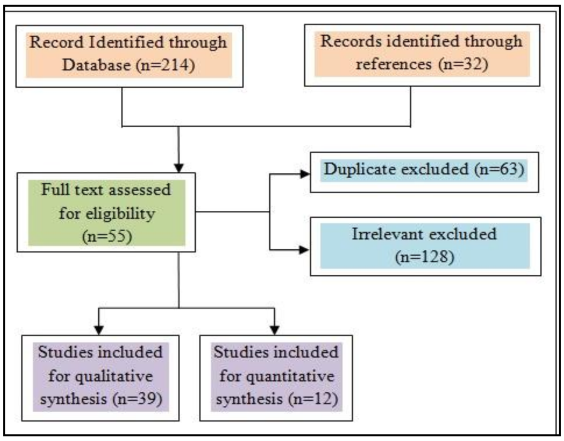

Figure 1: PRISMA flow diagram.

Table 2: Prisma based study table.

Authors (year)	Study design	Population/ disease	Micro perimeter	Comparator	Main functional outcomes	Key findings
Tian et al[5]	Comparative	Glaucoma (hemifield defect)	MAIA	SAP, SD-OCT	RS	Macular RS correlated with GCC thinning
Mosca et al[8]	Comparative	Localised glaucoma defects	MAIA	SAP, SD-OCT	RS, structure-function correlation	MP showed a closer structure-function correlation than SAP
Tepelus et al[9]	Comparative	NTG	MAIA	SAP	RS correlation	Strong agreement in macular sensitivity
Pilotto et al[10]	Imaging-functional	Geographic atrophy (AMD)	MP-1	en-face OCT	Scotoma Mapping, RS	MP precisely mapped atrophic functional loss
Laishram et al[11]	Observational	Macular diseases	MP-1	BCVA	Mean RS	MP detected functional loss despite preserved VA
Forshaw et al[12]	Cross-sectional	AMD	MAIA	Vision-related quality of life (QoL) scales	Macular sensitivity	RS correlated better with quality of life than VA
Sugimoto et al[13]	Retrospective	DME with good VA	MAIA	BCVA	RS	MP detected subclinical functional gain
Boned-Murillo et al[14]	Observational	Diabetic retinopathy	MAIA	OCT	Reduced RS	Reduced macular sensitivity despite preserved VA
Scuderi et al[15]	Narrative/ clinical review	Glaucoma with central field involvement	MAIA/ MP-3	SAP (HFA), OCT	Central RS, fixation, structure-function	Highlighted the added value of MP over SAP for detecting central glaucomatous dysfunction
Qian et al[16]	Interventional	Low-vision maculopathy	MAIA	-	Fixation stability and RS	MP biofeedback improved functional vision.
Liang et al[17]	Cross-sectional	Early POAG	MP-3	SAP, OCT	RS, GCC	MP-3 detected early macular dysfunction
Ihsan et al[18]	Prospective pilot	DME	MAIA	OCT	RS and CMT	RS improved despite minimal VA change

*Key comparative studies evaluating MP in macular and central retinal disorders. (Central macular thinning-CMT), glaucoma (Ganglion cell complex-GCC), DME and low-vision states (Retinal Sensitivity-RS).

RESULTS

The included studies comprised human observational, comparative, and interventional investigations evaluating MP in macular and central retinal disorders. Commercial devices (MP-1, MAIA, MP-3) were used, with outcomes compared against SAP, best-corrected visual acuity (BCVA), and OCT. Conditions studied included central-involving glaucoma, DME, AMD, inherited retinal disorders, and low-vision states.

In eyes with macular or paracentral involvement, MP reliably detected sensitivity loss corresponding to SAP while providing superior spatial localisation through fundus tracking and fixation monitoring.

In glaucoma, sensitivity loss aligned with ganglion cell complex thinning, whereas in macular disorders, it correlated with increased retinal thickness, outer retinal disruption, and macular oedema. Localised microperimetric measures demonstrated closer structure-function correspondence than BCVA. In DME, MP detected functional improvement following anti-vascular endothelial growth factor therapy, often despite minimal changes in BCVA, indicating sensitivity to treatment-related functional recovery. In AMD, MP quantified localised functional loss across disease stages, demonstrated progressive sensitivity decline in atrophic disease, and showed improvement following treatment. MP provided clinically relevant information on fixation stability and PRL in cases of central scotomas or unstable fixation. Rehabilitation studies reported improved fixation stability and functional visual performance.

The instrument

Conventional perimetry assesses the visual field by presenting light stimuli at minimal detectable intensities across predetermined retinal locations. Its software tracks stimulus presentation based on the selected test pattern, including the diameter, area, and number of measurement points. In contrast, MP incorporates real-time retinal tracking and continuous fixation monitoring, allowing precise alignment of each stimulus with the targeted retinal locus. For the evaluation of PRL, MP expresses fixation data in two forms: (i) the percentage of fixation points falling within standardised circles centred on the retinal image, and (ii) the mathematically derived BCEA, which defines the area and orientation of the ellipse that best represents fixation dispersion. Both clinical classification approaches were originally suggested by Fuji et al.[19]

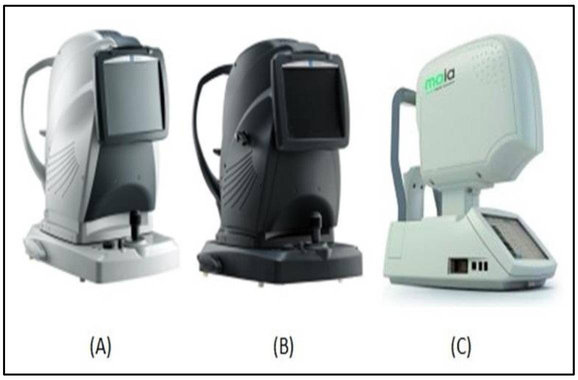

Figure 2 (A-C): A and B-MP-3 and MP-3 type S (scotopic microperimeters-NIDEK) and C- ICare MAIA (Confocal microperimeter-centerVue).

The SLO101 (Rodenstock Instruments, Munich, Germany; 1982) was the first microperimeter developed for fundus-mapped visual field assessment. It employed scanning laser ophthalmoscopy (SLO) technology with a modulated helium–neon (633 nm) laser, manually generating the background illumination and projecting stimuli within a 33×21° central retinal field. However, the system lacked an integrated eye-tracking mechanism and operated in a semi-automated stimulus delivery mode, which limited fixation compensation and functional precision.[11,20]

Advances in fundus-guided visual field testing resulted in the introduction of multiple next-generation MP systems, each integrating retinal imaging with sensitivity assessment. These platforms include the MP-3 system developed by Nidek Technologies (Padua, Italy), the OCT-integrated scanning laser ophthalmoscope-based microperimeter from Optos (Marlborough, USA), and the MAIA device introduced by CenterVue (Padua, Italy). Although each device has its own technical features, they share similar core functions. [21]

One key distinction is that the Optos OCT-SLO can overlay functional deficits directly onto cross-sectional OCT images as well as en face views, providing a detailed structure–function comparison. In contrast, the MP-3 and MAIA systems support scotopic MP, enabling testing under low-light (scotopic) conditions. (Figure 2).[22]

Advantages of MP

Real-time retinal monitoring

MP enables real-time detection and correction of eye movements at specific retinal locations. Stimuli are projected directly onto the retina with continuous eye-tracking, allowing reliable testing–retesting outcomes.[2,10,15,16,23-28]

Precise structure-function correlation

It directly links fundus morphology with retinal light sensitivity by presenting stimuli to targeted regions of interest, such as scotomas, enabling accurate functional mapping.

Effective in unstable fixation

Owing to continuous eye-tracking, MP does not require consistent foveal fixation. This makes it particularly valuable when foveal function or fixation stability is impaired.

Biofeedback for low-vision rehabilitation

The built-in biofeedback system helps train patients to shift from a preferred retinal locus (PRL) to a trained retinal locus (TRL) selected by the clinician, enhancing functional visual performance.

AMD

In both atrophic and neovascular AMD, MP offers a detailed functional assessment of visual quality and helps identify central scotomas. Reduced macular sensitivity correlates with AMD severity and progression. These functional deficits align with changes in microstructure, particularly in areas with RPE–drusen complex alterations, pigment epithelial detachment, subretinal fluid, and geographic atrophy. It is also useful for assessing response to anti-VEGF therapy.

DME

MP demonstrates that decreasing macular sensitivity reflects the severity of macular oedema. It is also valuable in evaluating the functional impact of different laser treatment modalities.

Glaucoma

Although SAP remains the gold standard for glaucoma monitoring, MP can better detect nerve fibre layer defects and eccentric fixation, especially in advanced stages.

Low-vision rehabilitation

In patients with central scotomas, MP-guided biofeedback training improves fixation stability, visual function, and overall quality of life.

Other macular disorders

MP is also effective for functional assessment in conditions affecting macular structure and function, including central serous chorioretinopathy, hydroxychloroquine maculopathy, rod-cone dysfunction, macular hole, and epiretinal membrane.

The infrared fundus camera continuously captures the fundus image, which is simultaneously tracked during perimetric testing, enabling visual field data to be mapped directly onto the retinal image. If the patient exhibits marked fixation instability, the test automatically pauses until fixation is regained.

After the perimetric assessment is completed, a colour fundus camera registers the infrared image. Additional fundus modalities, such as short-wavelength fundus auto-fluorescence, can also be imported into the instrument software for precise registration with visual field findings.

Sensitivity results may be displayed as numerical values, symbolic outputs, or interpolated colour-coded maps. The local defect map presents numerical deviations from the device's normative database and categorises abnormalities as suspect/relative scotoma/absolute scotoma.[1]

Parameters

Adaptation levels

Apart from similarities in spatial test patterns, stimulus sizes, and certain threshold strategies, several key differences exist between MP and the Humphrey field analyzer (HFA).

One major distinction lies in the background luminance used by the two devices. The microperimeter presents stimuli on a significantly lower background luminance compared to the HFA. Because of this, the visual pathways involved in detecting test lights under the HFA's brighter, photopic-adapting conditions may differ from those engaged under the mesopic background of the microperimeter, where stimuli delivered against a low mesopic background may be detected through a mixed rod and cone response or primarily via cone-mediated mechanisms.

The processes responsible for detecting visual stimuli are not uniform and vary according to several retinal factors, such as disease type and severity, retinal eccentricity, and the complex interactions between different photoreceptor systems.

In this context, MP has been shown to reveal more pronounced sensitivity loss than the HFA in patients with retinitis pigmentosa (RP), while identifying comparatively less extensive functional deficits in glaucoma. This pattern suggests that MP may offer enhanced performance in detecting RP-related functional impairment, while conventional perimetry remains more sensitive for glaucoma-related field loss.[4]

Dynamic range

An important distinction between the instruments is their dynamic range, which influences clinical interpretation of visual field results. Because the microperimeter has a restricted dynamic range of approximately 2 log units, its measurements are susceptible to notable ceiling and floor effects, particularly in eyes with macular disorders as well as in patients with retinitis pigmentosa (RP) and glaucoma. This restricts its ability to monitor patients whose defects are either too advanced or too subtle to fall within its measurable range.[4,14,30]

In healthy individuals, the microperimeter also exhibits a ceiling effect, resulting in a reduced apparent age-related decline in RS. However, despite this ceiling limitation, studies have demonstrated a linear relationship between threshold values obtained from the microperimeter and those measured using the HFA and the OPKO systems.[1,3,29]

Normative data

MP remains valuable for accurately identifying and quantifying visual field defects. The device's normative database is based on a 77-point, 10° circular grid, in which point spacing increases with eccentricity and uses the 4-2-1 threshold strategy.[14] However, when applying the 10-2 pattern, the microperimeter's local defect map, derived from its internal normative database, has been shown to overestimate defects compared with results obtained using Bayesian modelling.[3,4] Normal reference data from the microperimeter may also influence interpretation by increasing variability and producing lower sensitivity values in the superior retina. This effect is believed to result from an instrument-related artefact, which can be corrected mathematically.[31,32]

Retinal changes and the MP

AMD

In the early stages of AMD, MP has been applied to quantify visual sensitivity across discrete pathological regions, such as drusen deposits and areas of pigmentary change. By allowing precise co-registration of retinal structural features with functional sensitivity measurements, MP facilitates assessment of the differential impact of various morphological abnormalities on localised retinal function.

Notably, pigment epithelial detachments are associated with greater variability in RS compared with other manifestations of neovascular AMD, while retinal locations corresponding to neovascular complex frequently exhibit sensitivity values of 0 dB (Figure 3).[33]

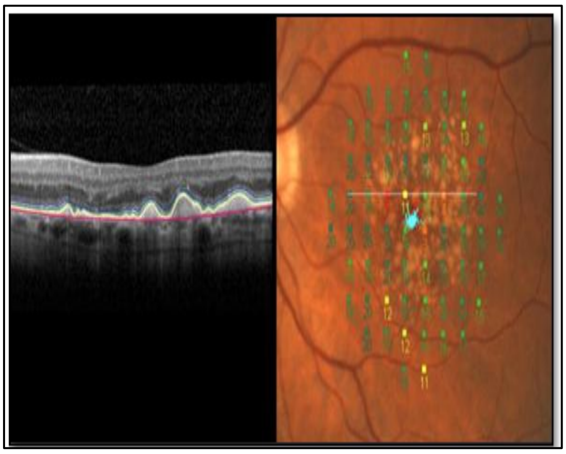

Figure 3: Segmented SD-OCT image of early AMD (left) showing Bruch's membrane (red), retinal pigment epithelium (yellow/green), and inner segment ellipsoid band (blue).

*The corresponding MP 10-2 field is overlaid on a colour fundus image (right), with the white line marking the OCT scan location.[35]

In late-stage AMD, where findings typically include retinal pigment epithelium disruption, loss of photoreceptor integrity, and macular oedema, MP has been instrumental in tracking functional decline. Studies have reported a progressive reduction in mean sensitivity over time, for instance, a measurable decline over two years in individuals with geographic atrophy, and over one year in patients with progressive atrophic macular disease who maintained stable visual acuity.[30]

MP has also served as a valuable functional outcome measure, demonstrating improvements in RS following pharmacologic therapy in AMD.[34]

Retinitis pigmentosa

MP has been proposed as a valuable functional outcome measure for clinical trials in retinitis pigmentosa (RP). In a study using red stimuli on a red background (1 cd/m^2), a strategy designed to reduce ceiling effects in RP-researchers found near-normal parafoveal sensitivities, with sensitivity progressively declining toward the periphery.[36,37]

Similar to its use in AMD, MP has helped clarify the relationship between retinal structure and function in RP. Short-wavelength fundus auto-fluorescence imaging in retinitis pigmentosa (RP) commonly reveals concentric hyper-auto-fluorescent rings. The location of the ring's inner boundary corresponds to the residual inner segment ellipsoid (ISe) band, also referred to as the photoreceptor inner segment/outer segment (IS/OS) junction.

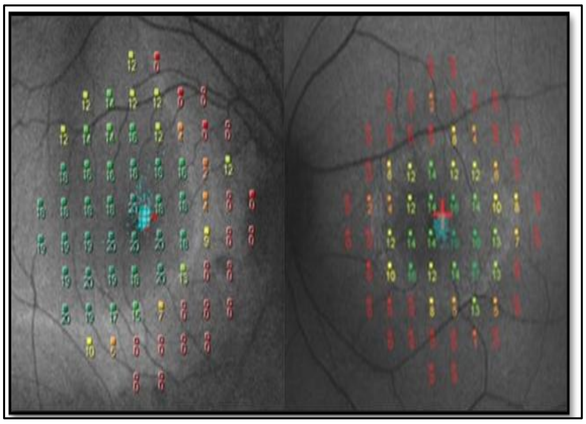

Figure 4: MP 10-2 test results obtained with the MP-1 device are overlaid on short-wavelength fundus auto-fluorescence images in two patients with retinitis pigmentosa.

Visual sensitivity is generally markedly diminished or absent beyond the hyper-auto-fluorescent ring, remains relatively intact within the ring, and subsequently decreases again across the hyper-auto-fluorescent region itself. Mean RS also shows a significant correlation with the area of normal-appearing auto-fluorescence inside the ring (Figure 4).

Stargardt disease

In ABCA4-associated retinal degeneration (Stargardt disease, STGD), MP is also considered a dependable tool for assessing macular function. Studies using red-on-red MP have shown reduced parafoveal sensitivity and comparatively better sensitivity in the perifovea among STGD patients. No association was found between overall sensitivity and test repeatability, suggesting that a single test-retest variability estimate is sufficient to identify meaningful changes in localised visual function.[38,39]

Because the peripapillary region tends to be relatively preserved in STGD, it has been highlighted as a potentially important area for evaluating treatment response. Detailed structural and functional assessment of this region is therefore valuable.

A recent study compared SD-OCT and MP findings in the peripapillary retina versus the central macula. In patients with extramacular involvement, visual sensitivity loss was greater in the temporal macula than in the nasal side, corresponding to abnormalities in photoreceptor layer thickness. The peripapillary region, however, showed less structural and functional impairment.

Another investigation classified STGD patients based on whether the photoreceptor IS/OS (ellipsoid zone) junction at the fovea was disrupted or lost, and MP demonstrated significantly different sensitivity levels between these groups.

Glaucoma

In patients with primary open-angle glaucoma (POAG), particularly those with central visual field involvement, MP has demonstrated RS measurements that are broadly comparable to those obtained with SAP, while providing additional advantages in precise macular functional mapping. Studies comparing macular-focused MP platforms such as MAIA with SAP have shown good agreement in detecting macular dysfunction in glaucomatous eyes.[5,6,17]

Importantly, MAIA has been shown to identify abnormal macular visual field defects that may remain undetected by conventional SAP, especially in eyes with early or subtle central involvement. These functional abnormalities detected by MP have been found to correlate closely with structural changes in the ganglion cell complex (GCC) thickness measured by spectral-domain OCT (SD-OCT), supporting a robust structure-function relationship at the macular level.

Furthermore, the use of newer testing patterns on MP devices such as the MP-3 has enhanced the detection of early central functional loss in POAG. In early glaucoma, MP-3 MP demonstrated high sensitivity in revealing macular dysfunction, even in cases where SAP results were within normal limits, suggesting that central visual field damage may exist before it becomes clinically apparent on standard perimetric testing. Collectively, these findings indicate that MP serves as a valuable complementary tool to SAP for the assessment of central visual field damage and early glaucomatous macular involvement.

Macular edema

In DME, MP has emerged as a valuable tool for both baseline functional assessment and monitoring response to therapy, as it provides localised RS measurements that extend beyond conventional visual acuity testing. In a prospective pilot investigation assessing the early response to intravitreal anti-vascular endothelial growth factor (anti-VEGF) treatment, a significant decrease in central macular thickness (CMT) was observed alongside a substantial improvement in RS as measured by MP, supporting a direct structure-function relationship at the macular level (Figure 5).[12,13,18]

Importantly, improvements in RS were observed even in cases where BCVA changes were minimal, indicating that MP can detect subtle functional gains that may not be captured by visual acuity alone. This observation is particularly relevant in DME patients with relatively preserved vision, where functional impairment may precede measurable acuity loss. In a retrospective observational study, Sugimoto et al reported significant post-treatment improvement in macular sensitivity following anti-VEGF therapy in DME eyes with good baseline vision, reinforcing the role of MP as a sensitive outcome measure in this subgroup.

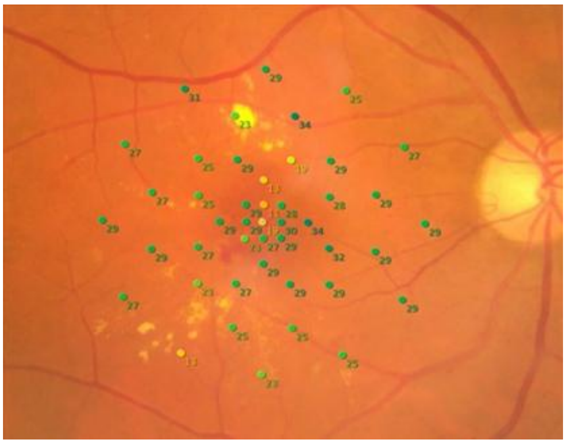

Figure 5: MP reveals more subtle functional deficits in DME patients than visual acuity alone.

Beyond anatomical and functional metrics, macular sensitivity assessed by MP has also been shown to correlate more closely with vision-related quality of life than visual acuity alone, emphasising its clinical relevance in evaluating patient-perceived visual function. Collectively, these findings support the use of MP as a complementary assessment tool in DME, capable of capturing functional improvement, treatment efficacy, and patient-centred visual outcomes that may otherwise be underestimated by standard acuity-based measures.

DISCUSSION

Assessment of macular and central retinal function is critical in patients with central visual field involvement, where conventional visual acuity alone may fail to reflect localised functional impairment. MP enables point-to-point mapping of RS within the central visual field, offering a functional evaluation that complements SAP in macular and central retinal disorders. Comparative studies have demonstrated a significant correlation between RS measured by MP and SAP, particularly in eyes with central or paracentral defects. In patients with glaucoma affecting the central visual field, MP has shown good agreement with SAP while providing enhanced detection of subtle macular dysfunction. Tepelus et al reported a strong correlation between RS obtained using MP and SAP in eyes with low-tension glaucoma, supporting the reliability of MP for evaluating central functional loss. Importantly, MP allows fixation-controlled testing, which is particularly advantageous in patients with unstable fixation or early macular involvement.[9]

Similarly, Lima et al demonstrated that MP was effective in identifying paracentral visual field defects in glaucomatous eyes, with sensitivity losses corresponding closely to defects detected on SAP, while offering superior spatial localisation of functional deficits within the macula. These findings suggest that MP may uncover clinically relevant central functional impairment that could be underestimated or overlooked by conventional perimetry alone.[7]

Furthermore, combined evaluation using MP, SAP, and SD-OCT has highlighted the importance of structure-function correlation in localised glaucomatous damage. Mosca et al showed that areas of reduced macular sensitivity on MP corresponded to localised structural changes on macular SD-OCT, reinforcing the role of MP as a functional bridge between visual field testing and retinal imaging.[8]

Despite its advantages in central visual field assessment, MP is limited by a narrower dynamic range and longer testing time compared with SAP. These factors restrict its standalone applicability in advanced disease stages or in conditions requiring peripheral visual field evaluation, emphasising that MP should be regarded as a complementary rather than a substitutive modality.[7-9]

Overall, an integrated approach using MP for detailed assessment of central retinal function and SAP for global and peripheral visual field evaluation provides the most comprehensive strategy for clinical assessment and longitudinal monitoring of patients with glaucoma and macular disorders.

CONCLUSION

Overall, MP provided a reliable assessment of central RS comparable to SAP, with added value in detecting localised macular dysfunction and treatment-related functional changes. Strong structure–function correlation and fixation analysis support its role as a complementary tool in macular disease, central glaucoma, and low-vision management.

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