Microperimetry — Comparison Between the Micro Perimeter 1 and Scanning Laser Ophthalmoscope — Fundus Perimetry

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• PURPOSE: To compare microperimetry using the scanning laser ophthalmoscope (SLO, Rodenstock, Germany) and the recently introduced Micro Perimeter 1 (Nidek Technologies, Italy).

• DESIGN: Prospective comparative observational study.

• METHODS: Fundus perimetry with static threshold perimetry was performed using the SLO and the MP1 in 68 eyes of 40 consecutive patients with different retinal diseases for example, central serous chorioretinopathy, macular dystrophy, and age-related macular degeneration. With both instruments, an automated 4–2-1 staircase strategy with Goldmann III stimuli and a comparable number of stimuli were applied. The depth and size of the detected scotomata as well as the location and stability of fixation were compared between both instruments.

• RESULTS: There was good concordance of results, with 75% (51 of 68 eyes) showing an equal defect. Whereas the MP1 showed larger defects (depth and size) in 23.5% (16/68) of eyes studied than the SLO, the defects appeared larger with the SLO in 1 eye. Concerning fixation analysis, similar results were found for fixation stability with stable fixation in 47.1% (MP1: 32/68) and 48.5% (SLO: 33/68) and likewise for the location of fixation with foveal fixation in 54.4% (37/68) with the MP1 and the SLO. Whereas the average number of stimuli was similar for both instruments (MP1 56.8 ±16.1, SLO 62.9 ± 17.0), examination time was prolonged with the MP1 (MP1: 11m35s ± 3m47s, SLO: 10m29s ± 3m23s). Throughout all examinations, fundus visualization with the SLO was superior to the MP1.

• CONCLUSIONS: For automated threshold microperimetry the MP1 provides results comparable to our SLO perimetry. Both instruments enable detection of sensitivity loss of the central visual field and an analysis of fixation behavior during microperimetry. Nevertheless, the MP1, with its automated real-time image alignment, facilitates examination. Additionally, the enlarged field allows testing in an area of 44 × 36 degrees instead of the 33 × 21 degree-area of the SLO. However, in comparison to our SLO-software, the current software of the MP1 requires improvements before exact measurements of defined retinal diseases are possible. (Am J Ophthalmol 2005;139:125-134. © 2005 by Elsevier Inc. All rights reserved.)

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FUNDUS PERIMETRY OR MICROPERIMETRY HAS BEEN used clinically for assessment of macular function in the past.[1–7] Exact correlation between fundus pathology and corresponding functional defects is achieved by integrating fundus imaging and computerized threshold perimetry. Previous studies have shown the value of this method for follow-up of patients suffering from progressive macular diseases.[8,9]

In the past, the scanning laser ophthalmoscope (SLO, Rodenstock, Germany) was the only commercial available microperimeter. But important software features such as real-time fundus tracking were lacking, and the SLO covered a field of view of only 33 × 22 degrees. Additionally, the SLO is no longer available for purchase. Recently, a new instrument called the Micro Perimeter 1 (MP1, Nidek Technologies, Italy) has been introduced. This instrument allows for fundus perimetry in a larger field with automated full-threshold perimetry software. Furthermore, real-color fundus image acquisition is possible; an overlay of the perimetric findings onto the fundus image is also possible.

The aim of this study was to compare both instruments in their ability to assess the function of the macula and central visual field as well as the location and stability of fixation in patients with macular diseases. We compared

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TABLE 1. Diagnoses and Number of Examined Eyes of all Patients Presenting With Different Forms of Retinal Diseases and Central Visual Field Defects

Diagnosis	Number
Central serous chorioretinopathy	14
Juvenile macular dystrophy	20
Stargardt's disease	14
Age-related macular degeneration	11
Macular hole	2
Retinal scars	5
Cone-rod-dystrophy	2
Total	68

the perimetric results, the behavior of fixation, the image quality of the two devices as well as additional software options.

METHODS

• **PATIENTS:** Sixty-eight eyes of 40 consecutive patients (19 men and 21 women) aged 11 to 87 years (42.7 ± 17.9 years) were included into this study after written informed consent after complete information concerning the study.

Each patient underwent routine ophthalmologic examination, including funduscopy with a Goldmann three-mirror contact lens and determination of best-corrected central visual acuity. The best-corrected visual acuity was on average 20/50, ranging from 20/800 to 20/16. Pupils were dilated with 1% tropicamide and 5% phenylephrine before examination. Thirty-four right and 34 left eyes with different retinal or choroidal lesions were examined in this study (Table 1). In all patients, the refractive media were sufficiently clear to perform fundus perimetry without difficulties. Both examinations were performed in random order by the same experienced operator. A prospective comparative observational study was performed.

• **SCANNING LASER OPHTHALMOSCOPE SLO 101:** We performed static threshold fundus perimetry with documentation of fixation using the SLO 101 with the software developed by our laboratory.[4,10,11] Stimulus size was Goldmann III, presentation time was 120 ms, background illumination was 10 cd/m^2, and we used a 4–2-1 -staircase strategy as described earlier.[3,9] Correction for fixation was performed by a landmark on the fundus interactively defined by the operator. Stimuli were presented using a modulated HeNe laser, that is, red light with 633 nm, whereas fundus imaging was performed with infrared light. The test grid was chosen according to the central fundus pathology with 38 to 117 (62.9 ± 17.0) stimulus locations. The area of examination covered up to 33 × 22 degrees. For evaluation of fixation, standard deviation around the mean fixation point during the microperimetric examination was recorded and analyzed. As a parameter that is inversely correlated with the stability of fixation, a standard deviation of less than 0.6 degrees around the mean fixation point indicated sufficient stable fixation.[11] Accordingly, fixation was regarded as "stable" if the standard deviation was less than 0.6 degrees, as "relatively unstable" if it was between 0.6 and 1.2 degrees, and as "unstable" if the standard deviation was greater than 1.2 degrees.

• **MP1 MICRO PERIMETER:** In comparison to SLO fundus perimetry, we performed similar examinations with the Micro Perimeter 1 (Nidek Technologies, Italy) using the software version available in June 2003 (Version: MP1 SW 1.4.1. SP1) with automated correction for eye movements. In contrast to the HeNe laser of the SLO, the Micro Perimeter 1 (MP1) uses a liquid crystal display to project stimuli. Instead of a manual correction for eye movements, it includes an automated tracking system to correct eye movements. At the beginning of the examination, an infrared camera (resolution of 1 pixel, equivalent to 0.1 degree) tracks a reference frame and an area of interest is defined. During examination, any eye movement is detected by image acquisition with 25 frames per second. The computer then calculates the shift between the reference image and the real-time fundus images with the stimulus position on the display corrected according to the actual location of the fundus. The MP1 device further enables the acquisition of color fundus photography at the end of the examination with an overlay of the perimetric findings onto this color fundus image.

The MP1 offers either the option to define a region of interest followed by an automatic determination of possible stimulus locations in a regular grid or to select a specific test grid before examination. In contrast to the SLO, it is not possible to define the test grid on the fundus image. Goldmann III stimuli and a 4–2-1-staircase strategy were used with the MP1 as well and the test grid and size was chosen according to the expected pathology in a maximal area of 44 × 36 degrees and included 35 to 90 (66.8 ± 16.1) stimulus locations. The stimuli were projected on a red background, analogous to the SLO, with background illumination set to 0.95 cd/m^2. Stimulus presentation time was either 100 or 200 ms. The perimetric strategy of the current software-version of the MP1 starts at the threshold level that is chosen before examination for each stimulus. Although the examiner can define the initial threshold value, there are no adaptive test strategies (e.g., Swedish Interactive Threshold Algorithm [SITA]) that shorten the lengthy staircase threshold procedure. However, it is possible to examine with a double staircase (4–2) strategy as well.

For assessment of fixation, the fundus movements are tracked during examination while the patient gazes at the fixation target. The autotracking system calculates horizontal and vertical shifts relative to a reference frame and returns a map of the patient's eye movements during the

TABLE 2. Important Hardware and Software Parameters (according to the manufacturer) of the MP1 and SLO Fundus Perimetry Used in This Study

Parameter	MP1	SLO
Field	36 × 44 degrees	33 × 21 degrees
Background illumination	0.95 cd/m^2	10 cd/m^2
Background color	red	red
Stimulus size	Goldmann III	Goldmann III
Stimulus color	white	red
Projection method	LCD-display	modulated HeNe laser (633 nm)
Stimulus intensity:		
Maximal luminance	0 dB = 127 cd/m^2	0 dB = 72 cd/m^2
Maximal attenuation	20 dB	23 dB
Stimulus duration	100 or 200 ms	120 ms
Fixation target	cross of 1- or 2-degree diameter, red color luminance	cross of 1.5- × 1.5-degree diameter, red color luminance 15 cd/m^2

examination. The recorded fixation points are classified into three categories for fixation analysis termed "stable," "relatively unstable," and "unstable." Fixation is regarded as "stable" if more than 75% of the fixation points are inside the 2-degree diameter circle, as "relatively unstable" if less than 75% are inside the 2-degree diameter circle but more than 75% are inside the 4-degree diameter circle, and as "unstable" if less than 75% of the fixation points are inside the 4-degree diameter circle. The important parameter settings of both instruments are given in Table 2.

• **COMPARISON OF PERIMETRIC RESULTS:** Perimetric results of both instruments were analyzed for functional defects and fixational stability. A reduction of the differential light threshold was categorized as an "absolute scotoma" when one or more stimuli were not seen with the brightest stimulus (0 dB). It was categorized as a "relative scotoma" when a circumscribed area of reduced differential light threshold could be found and as "general reduced differential light threshold" when the threshold values were reduced to the same threshold level in the whole area examined. If an area of absolute scotoma was detected, the defect was considered to be an "absolute" scotoma regardless of other areas analyzed.

Both the MP1 and the SLO were investigated for their ability to detect the preferred retinal locus (PRL) and to measure fixation stability during perimetry. Therefore, the location of the PRL was categorized on the basis of the fundus image into "foveal," "parafoveal," "extrafoveal," or "alternating." Fixation stability was analyzed and classified into three categories according to the MP1 classification. With regard to perimetric results and fixation behavior, the results of both instruments were compared intraindividually for each eye examined.

For comparison of perimetric findings and behavior of fixation between both methods, the data were arranged in a 4 × 4 or 3 × 3 cross table. The agreement between both methods was estimated using Cohen's κ coefficient of agreement. The degree of concordance was moderate for κ 0.41 to 0.60, substantial for 0.61to 0.80 and almost perfect for κ 0.81 to 1.00.[12]

Maximum retinal irradiance of the scanning laser ophthalmoscope was well below the limits established by the American National Standards Institute and other international standards (ANSI Z136.1; 1993). The study followed the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Heidelberg.

RESULTS

ALL EYES INCLUDED COULD BE EXAMINED WITH BOTH techniques. There was good concordance of results; however, MP1 fundus perimetry showed a larger defect in size and/or in depth when compared with SLO perimetry in 16 of 68 eyes (23.5%) (Table 3, Figure 1). In 51 eyes (75%), the defect was equally detected as absolute or relative scotoma with both instruments (Figure 2), whereas the defect was larger with the SLO in 1 eye (1.5%). When comparing perimetric findings according to the scotoma depths as absolute or relative scotoma, as diffuse reduction or as normal, there was nearly substantial agreement between the SLO and MP1 perimetry (Table 3, κ 0.590).

The PRL found during microperimetry was similar for both instruments with foveal fixation in 54.4% (37 of 68 eyes) (MP1 and SLO), agreement between both instruments was also substantial (Table 4, κ 0.683). Additionally, the stability of fixation was comparable for both techniques with stable fixation in 47.1% (MP1: 32/68) vs 48.5% (SLO: 33/68) and moderate agreement (κ 0.480). Likewise, instable fixation was found in 11.8% (8/68) with both instruments (Table 4). In one patient, fixation analysis with the MP1 produced an artifact. While the patient was gazing steadily at the fixation target proved by the infrared image, a change of the PRL was recorded,

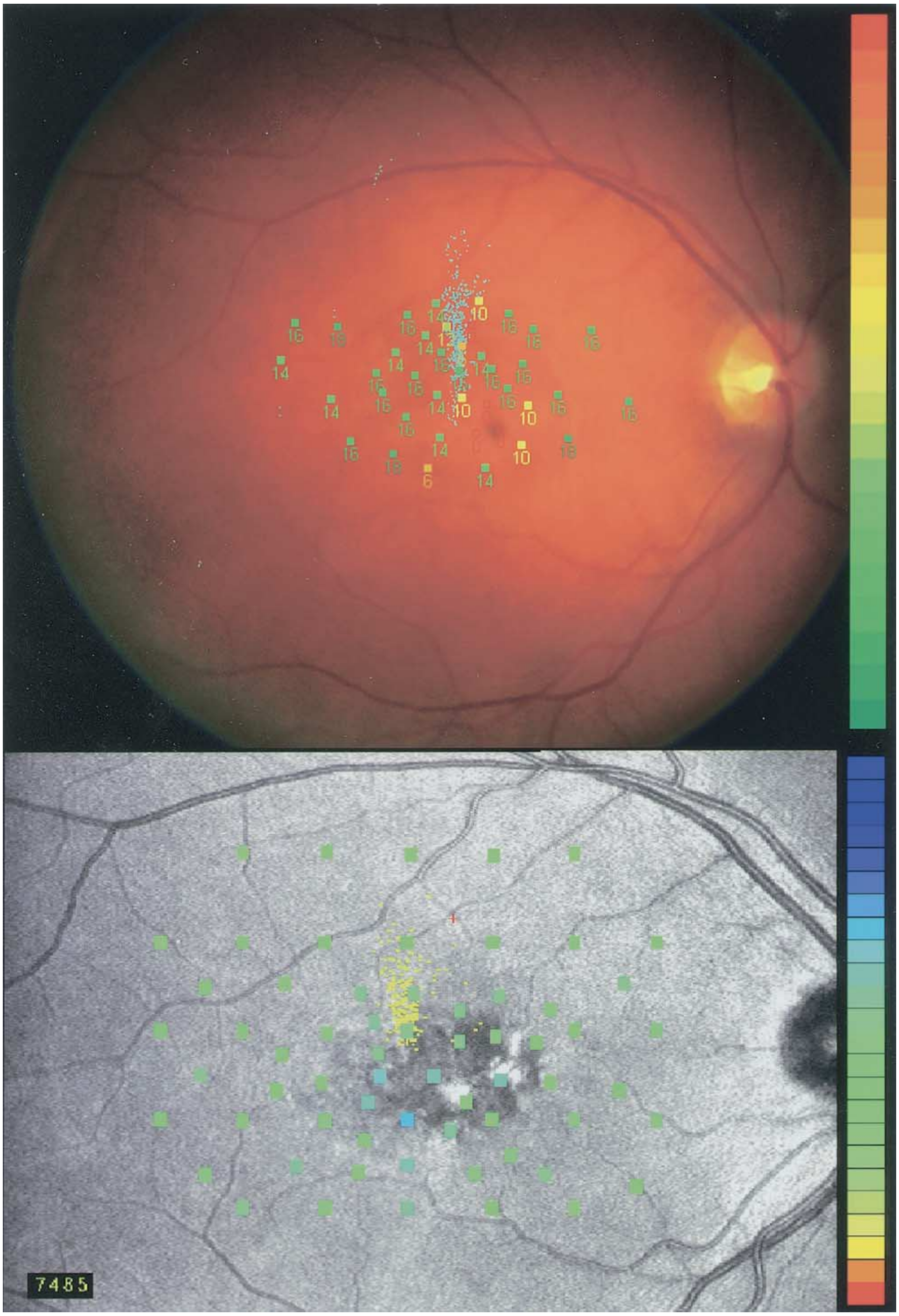

FIGURE 1. Right eye of a 37-year-old patient suffering from juvenile macular dystrophy. Fundus perimetry using the MP1 showed a large absolute central scotoma (top) while there was only a relative scotoma of about the same size using the SLO (bottom). The color-coded scale on the right shows the threshold in 1-dB steps beginning with 0 dB on top for both instruments. Open rectangles represent stimuli not seen at 0 dB.

probably because of a non-characteristic reference area chosen at the beginning of the examination.

Fundus visualization during the examination with the SLO was superior to the MP1 in all eyes. Because the black-and-white infrared image during MP1 examination is only of minor quality (Figure 3), it is often very difficult to delineate small retinal pathologies. The MP1 did not allow for the addition of stimuli after the beginning of the examination. Because of this, the exact delineation of a scotoma was sometimes missed when there were no test points outside areas of retinal pathology (Figure 4).

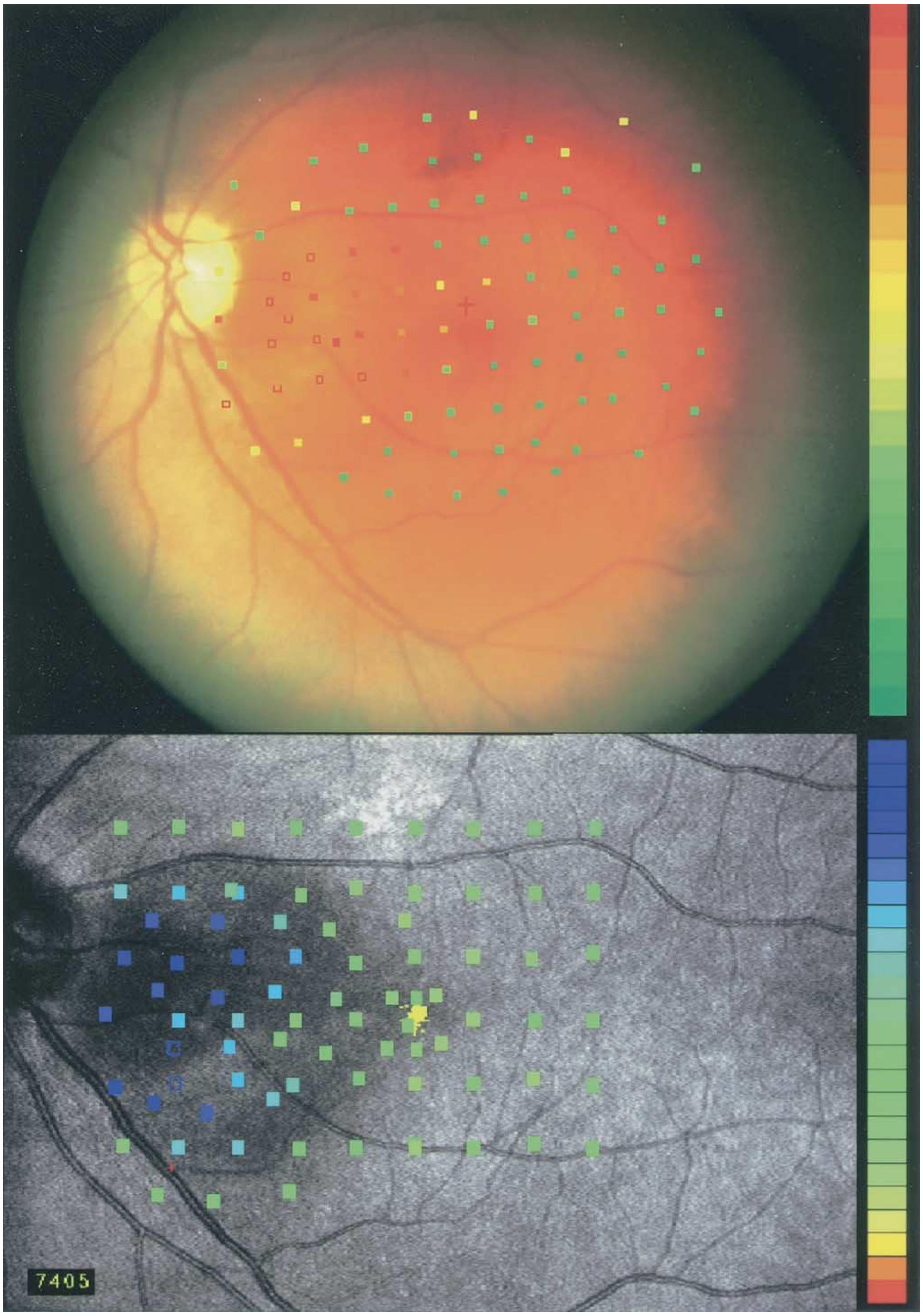

FIGURE 2. Left eye of a 40-year-old patient suffering from central serous chorioretinopathy. Fundus perimetry using the MP1 (top) and the SLO (bottom) came up with concordant findings concerning area and depth of the scotoma. The color-coded scale on the right shows the threshold in 1-dB steps beginning with 0 dB on top for both instruments. Open rectangles represent stimuli not seen at 0 dB.

According to the perimetric software of the MP1, examination time for a comparable number of stimuli (MP1 56.8 ± 16.1, SLO 62.9 ± 17.0) was slightly higher as with our own SLO software (MP1: 11m35s ± 3m47s, SLO: 10m29s ± 3m23s) (Table 5), where adaptive threshold levels are used[3,10,13]; still, this difference was not significant.

However, the great advantage of the MP1 is an automated real-time image alignment, resulting in high accuracy of stimulus presentation, which was possible in all eyes

TABLE 3. Perimetric Findings (absolute and relative frequency) Classified Into Absolute and Relative Scotoma, General Threshold Reduction, and Normal Findings Showed Nearly Substantial Agreement Between Both Methods (kappa = 0.590; n = 68)

	Perimetric Results	SLO: Absolute Scotoma 32 (47%)	SLO: Relative Scotoma 21 (30.9%)	SLO: General Reduction of Differential Light Threshold 12 (17.6%)	SLO: Without Pathologies 3 (4.4%)
	Absolute Scotoma 41 (60.3)	31 (45.6%)	8 (11.8%)	2 (2.9%)	
	Relative Scotoma 20 (29.4%)	1 (1.5%)	13 (19.1%)	4 (5.9%)	2 (2.9%)
MP1	General Reduction of Differential Light Threshold 6 (8.8%)			6 (8.8%)	
	Without Pathologies 1 (1.5)				1 (1.5%)

TABLE 4. Location of Fixation (PRL) and Stability of Fixation Given as Absolute and Relative Frequency Showed Moderate to Substantial Agreement (n = 68)

	Preferred Retinal Locus	SLO: Foveal 37 (54.4%)	SLO: Parafoveal 16 (23.5%)	SLO: Extrafoveal 15 (22%)	SLO: Alternating	SLO: Artifact
	Foveal 37 (54.4%)	32 (47%)	5 (7.4%)			
	Parafoveal 15 (22%)	5 (7.4%)	9 (13.2%)	1 (1.5%)		
MP1	Extrafoveal 15 (22%)		1 (1.5%)	14 (20.6%)		
	Alternating					
	artifact 1 (1.5%)		1 (1.5%)			

	Stability of Fixation	SLO: Rel. Unstable 27 (39.7)	SLO: Stable 33 (48.5%)	SLO: Unstable 8 (11.8%)
	Stable 32 (47.1%)	26 (38.2%)	6 (8.8%)	
MP1	Rel. unstable 28 (41.2%)	7 (10.3%)	17 (25%)	4 (5.9%)
	Unstable 8 (11.8%)		4 (5.9%)	4 (5.9%)

examined. After completing the examination, it was possible to get an overlay of the perimetric findings onto a real colored fundus image.

DISCUSSION

FOR AUTOMATED THRESHOLD MICROPERIMETRY, THE MP1 provides results comparable to the well-established SLO. The MP1 provides a major step forward in automated fundus perimetry by enabling exact real-time image alignment, even in patients with unstable fixation. The current software and fundus perimetry options of the MP1 show high sensitivity in detecting functional defects in the central visual field and provide good analysis of fixation behavior.

Perimetric results proved to be comparable to the results obtained with the SLO. There were no eyes where the location of scotomas was completely different. However, the extent and depth of scotomas differed between both set-ups (Figure 1 to Figure 2). Surprisingly, the MP1 revealed deeper defects than the SLO, despite the fact that the MP1 is, according to the manufacturer, capable of higher maximal stimulus luminance and a lower background illumination (Table 2). The MP1 group was composed of cases with different stimulus presentation time (100 ms and 200 ms), because the maximum time over which temporal summation can occur in normal eyes is

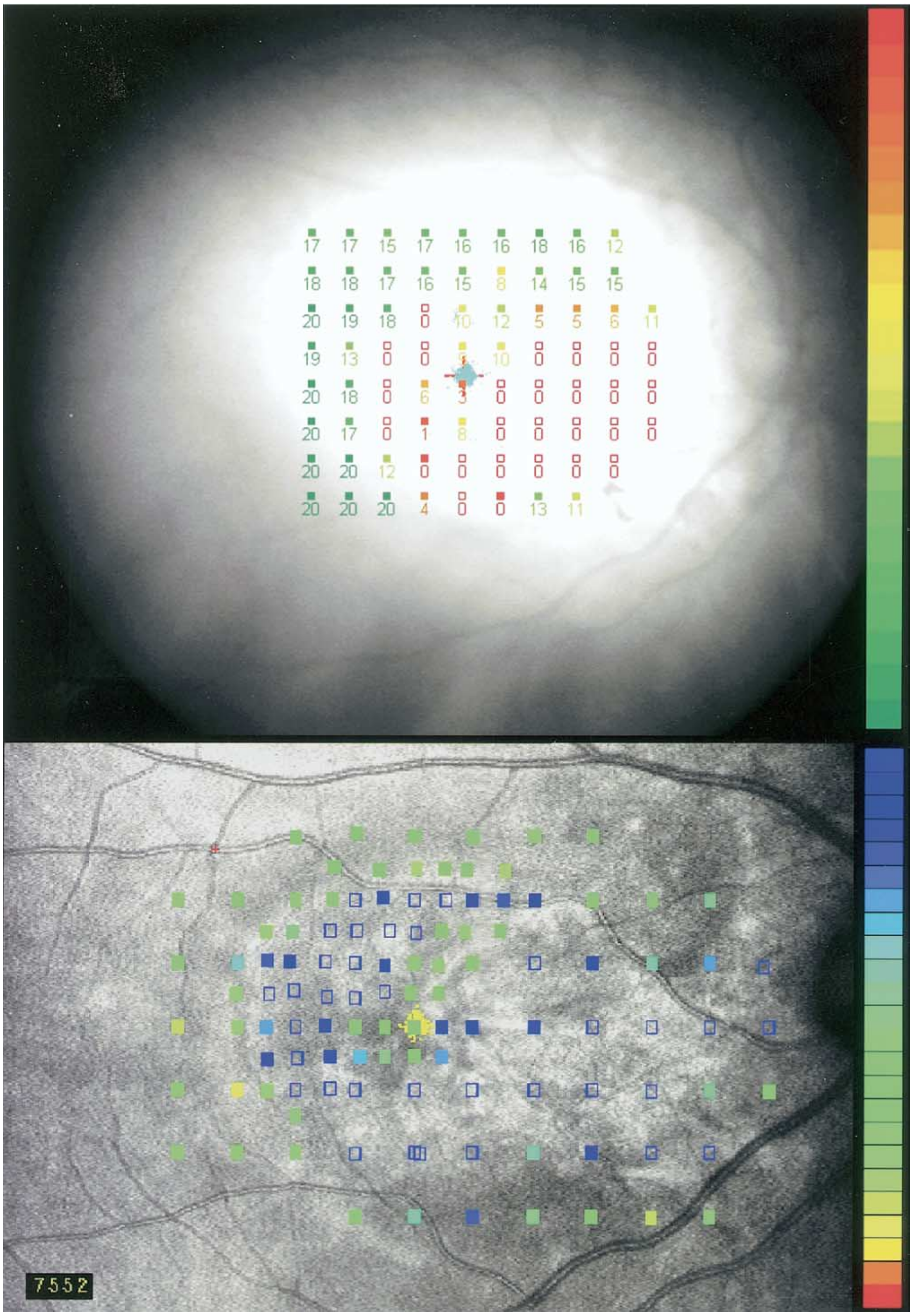

FIGURE 3. Right eye of a 29-year-old patient suffering from macular degeneration. It is nearly impossible to clearly detect the retinal pathology of the black-and-white image obtained with the MP1 (top), whereas the result of fundus perimetry using the SLO shows good concordance between morphologic alteration and central scotoma (bottom). The color-coded scale on the right shows the threshold in 1-dB steps beginning with 0 dB on top for both instruments. Open rectangles represent stimuli not seen at 0dB.

supposed to be complete at 100 ms (Bloch's law),[14] and differential light threshold with the MP1 seems to be mainly independent from stimulus duration (unpublished data).

Fixation analysis showed comparable results, although the methods of fixation recording differed between both instruments. Whereas the MP1 continuously registers fixation behavior by automated real-time fundus tracking and alignment, SLO fixation analysis depends on manual fundus tracking of the operator.[10,11] With both instruments, fixation analysis is limited to times when the eye is well aligned. The MP1 underestimated the eye movements

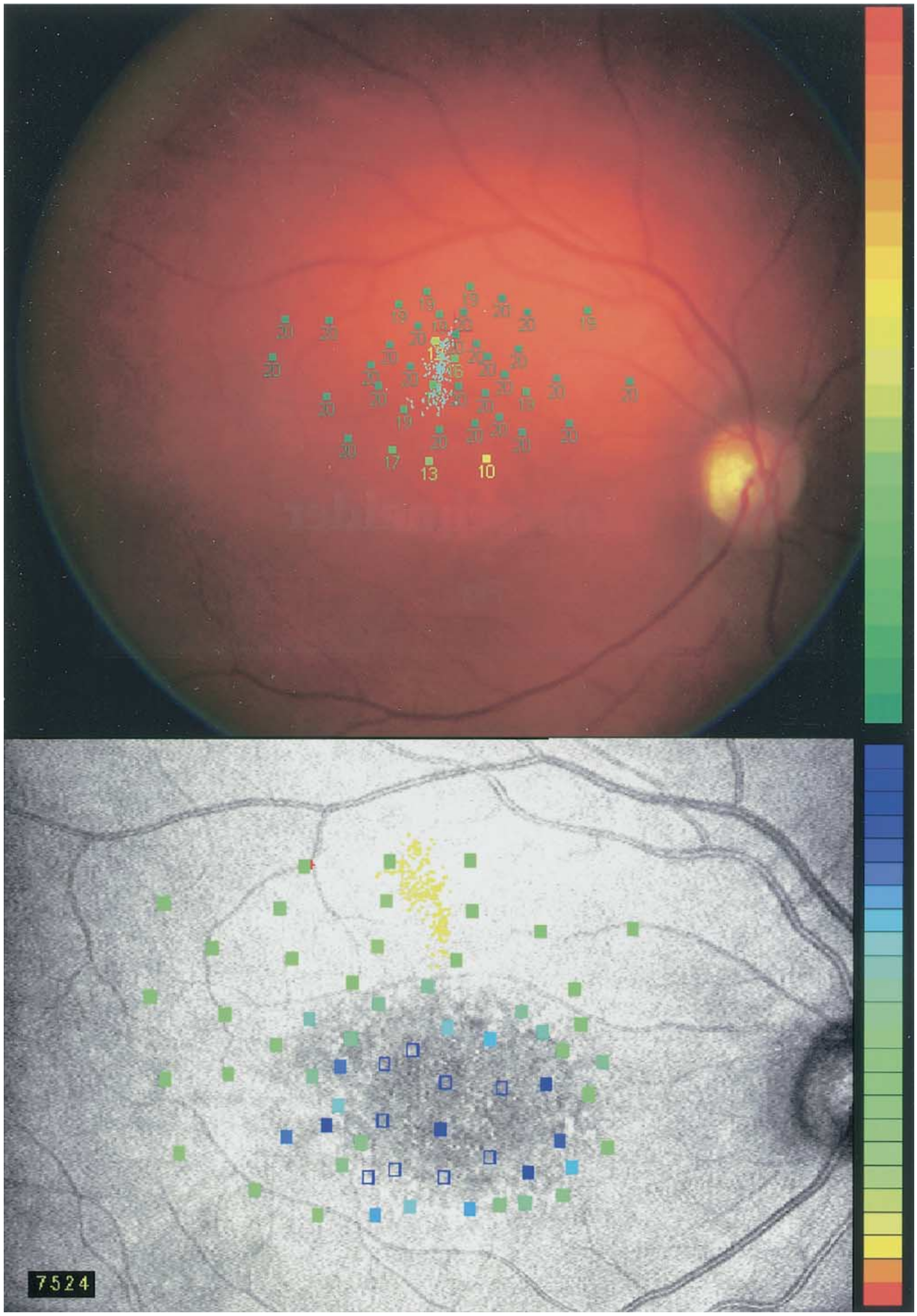

FIGURE 4. Right eye of a 45-year-old patient suffering from Stargardt's disease. Initial definition of the test grid did not completely cover the scotomatous area. Hence, the inferior margin was not delineated with the MP1 (top). In contrast, with the SLO there is the option of adding stimuli even after completing the examination (bottom). The color-coded scale on the right shows the threshold in 1-dB steps beginning with 0 dB on top for both instruments. Open rectangles represent stimuli not seen at 0dB.

during an examination by disrupting the examination procedure when the tracked reference area shifts too far out of the window frame. Unfortunately, the auto-tracking system cannot be inactivated to perform a perimetry manually in eyes with instable fixation or a wide range of eye movements. Similar to the SLO, fixation points are only recorded when the operator triggers a stimulus when the eye is well aligned. However, the MP1 seems to be a more reliable instrument for fixation analysis.

In the light of these differences, we would emphasize that limitations in the comparability of the two devices exist. These include different stimulus presentation meth-

TABLE 5. Number of Stimuli and Duration of Examination (no significant difference between both instruments), n = 68

	Parameter	MP1	SLO
No. of stimuli	Mean ± standard deviation	56.8 ± 16.1	62.9 ± 17.0
	Minimum	35	38
	Maximum	90	117
Duration of examination	Mean ± standard deviation	11m35s ± 3m47s	10m29s ± 3m23s
	Minimum	5m01s	5m06s
	Maximum	20m51s	21m46s

ods, different stimulus color, and different criteria for fixation stability. Nevertheless, the MP1, with its automated real-time image alignment, facilitates examination and the enlarged field allows for testing in an area greater than the 33 × 22 degrees of the SLO.

Although the current software of the MP1 is a major step forward in comparison to the original software of the SLO, especially outside the United States, it needs further improvement to optimize perimetry. There is no option to project the chosen test grid onto the fundus image before examination, which would allow for testing specific locations of fundus pathology. Therefore, it is impossible to exactly define scotoma borders after the examination has started when the first chosen test pattern does not include these areas (Figure 4). With the software version used in this study, it was not possible to add specific stimulus locations after the examination had started. However, after this study was completed, a new version was released allowing the option to refine the test grid and add specific stimulus locations. Further software improvement may reduce examination time and even include new faster test strategies.

A major disadvantage of the MP1, at the moment, is the image quality of the first acquired black-and-white infrared image used for eye tracking during the examination (Figure 3). To achieve a satisfying contrast between retinal vessels and the fundus, which is necessary for the auto-tracking system, a high level of infrared illumination has to be used. This often results in artifacts within the center of the infrared image, which makes a reliable detection of retinal pathologies and test pattern placement very difficult. As with the use of the SLO, the need for a control person during the examination is still necessary.

Besides static threshold fundus perimetry, it would be of additional help to have the option of performing kinetic fundus perimetry with the MP1 as well. In eyes with macular pathology, exact delineation of the size of scotomas would be much easier, and examination time could be reduced as we have found with the SLO. Although the SLO offers better imaging capabilities in general, that is, autofluorescence and fluoresceine angiography, the option of the MP1 to overlap the microperimetric results with a digital real-color fundus image provides valuable documentation and is helpful, even for the ophthalmologist who is not familiar with infrared images.

In conclusion, the major drawbacks of the Micro Perimeter 1 are the low quality of black-and-white infrared images during the examination and the possibility to miss defining a specific test grid on base of the fundus image. However, the MP1 is a major step towards an automated fundus perimetric examination. With real-time fundus tracking and color visualization of the fundus, the MP1 microperimetry provides comparable results to SLO fundus perimetry. Future development may allow to reduce examination time and simplify the use of the instrument.

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