Microperimetry: a review of fundus related perimetry

Michael D. Crossland,[1] Mary-Lou Jackson,[2] William H. Seiple[3]

[1]UCL Institute of Ophthalmology and Moorfields Eye Hospital NHS Foundation Trust, London, UK; [2]Massachusetts Eye and Ear Hospital and Harvard Department of Ophthalmology, Boston, MA, USA; [3]Lighthouse International New York, NY, USA

Abstract

Visual field assessment is a key part of optometry and ophthalmology practice. However, in people with non-central or unstable fixation, it is not possible to relate defects on a visual field map to a specific retinal location. Microperimetry (or fundus related perimetry) is a technique that images the retina during visual field testing, enabling a correlation to be made between visual function and retinal structure. In this article, the history of fundus related perimetry is reviewed. Three modern microperimeters (MP-1, OCT/SLO and MAIA) are described and their relative merits identified. Finally, the uses of microperimetry in optometric practice are discussed.

Introduction

Visual field assessment (perimetry) is a key part of optometric and ophthalmological practice. It is an essential part of diagnosing and detecting progression in many eye diseases. Assessment of visual field sensitivities can determine the likely function of people with visual impairment, and the extent of visual fields can predict whether people are able to drive safely or to work in some professions.

Historically, visual fields were generally measured using manual techniques such as confrontation, a tangent screen, the Friedman visual field analyzer or the Goldmann perimeter. However, automated perimeters such as the Humphrey, Henson and Dicon visual field analyzers are now more commonly used. Although these systems are very well established for conditions such as glaucoma, and have been shown to be reliable[1] and repeatable,[2] there are significant problems when measuring visual fields in people with central visual field loss.

Visual field measurement with non-foveal fixation

One problem with conventional visual field assessments is that the visual field plot produced is related to the position of gaze, normally the fovea. If the patient is using a non-foveal point for fixation then the plot of the area of visual field loss cannot be related back to the retina. For example, Figure 1 shows a Humphrey visual field plot for a person with age-related macular degeneration. From this examination it is not possible to detect whether the person is fixating with their fovea and the field loss is parafoveal (red arrow), or whether the person is fixating with retina to one side of the fovea and the area of field loss corresponds to the fovea (blue arrow).

The fovea could be at either of the locations to which the arrows point. Furthermore, at any point in time, the fovea could be anywhere inside the ellipse.

It is known that most people with macular disease develop a preferred retinal locus (PRL) for fixation in peripheral retina.[3-5] If this preferred retinal locus is well defined and used for all tasks, then the position of any field loss identified on a conventional perimeter can be inferred. However, it is known that the PRL can move depending on the task[6] and the luminance of the target.[7]

If the visual field loss is relatively small, and the test pattern extends over the optic disc, then the position of the physiological blind spot (PBS) corresponding to the optic disc can be used to determine the position of the fovea (Figure 2). However, this technique cannot be used in people with large scotomas that may encompass the optic disc, or in those with poor fixation stability.

Visual field measurement with unstable fixation

It is also known that fixation stability is reduced in people with macular disease.[8] This is significant as fixation moves during a visual field assessment; the size of any non-seeing region may be measured inaccurately (see the red ellipse on Figure 1). For example, a small scotoma may be detected by several different perimetry targets as the eye moves during the test. Alternatively, an absolute scotoma may be detected as a relative scotoma if a perimetry target is seen once at the point of the visual field corresponding to the scotoma.

Many automated perimeters give reliability indices. False negative responses are measured by repeating a stimulus that is seen comfortably, and checking whether the patient still reports the light as seen. False negatives may be caused by unstable fixation: a point could have been presented over relatively healthy retina at the first presentation, but as the eye moves due to unstable fixation it could be presented over a retinal lesion at its second presentation. False positives are identified by not presenting a stimulus when one might be expected, and ensuring that the patient does not respond to the light. False positive responses may be associated with being *trigger happy* or to having variable fixation: the expected location of the optic disc could have moved during the visual field test. Reliability indices should be checked on every visual field test, and particular attention should be paid to these values in people with central field loss. In general, a value of 33% false positive or 10% false negatives would be considered too high.[9] Further reliability indices include fixation losses (identified by presenting a target inside the physiological blind spot and ensuring the patient does not respond) and short-term fluctuation (available on some test strategies on the Humphrey field analyzer).

Some modern perimeters, such as the newer model Humphrey Visual Field Analyser, include an eyetracker to measure the position of gaze during the field test. However, the perimeter does not correct for these changes in eye position.

Microperimetry

A more accurate way to measure visual fields in people with central vision loss is to

Correspondence: Michael D. Crossland, UCL Institute of Ophthalmology and Moorfields Eye Hospital NHS Foundation Trust, London, UK.
E-mail: m.crossland@ucl.ac.uk

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perform the visual field test while simultaneously observing the retina. This allows the operator to know at which point of the retina each stimulus is being presented. This technique can correct for both non-central fixation and for unstable fixation.

The term *microperimetry* was first used in the peer-reviewed scientific literature by Jean *et al.* in 1990 when describing a scanning laser ophthalmoscope technique.[10] However, the term microperimetry is slightly misleading: the size of the target is the same as in conventional perimetry, and the extent of the visual field measured can be similar in size to a conventional perimeter. Some authors use the term *fundus perimetry* or *fundus related perimetry* instead, which is probably a more descriptive term.

Methods of review

This review article presents the findings of all papers that have been published in the peer-reviewed literature on microperimetry. A PubMed search was performed with key words *microperimetry OR fundus perimetry OR fundus related perimetry*. Web of Science (http://wok.mimas.ac.uk) was used to identify forward citations from key papers in this field. Conference abstracts were searched from the Association for Research in Vision and Ophthalmology (ARVO) and American Academy of Optometry (AAO) meetings. In total, 362 relevant publications and 334 conference abstracts were identified.

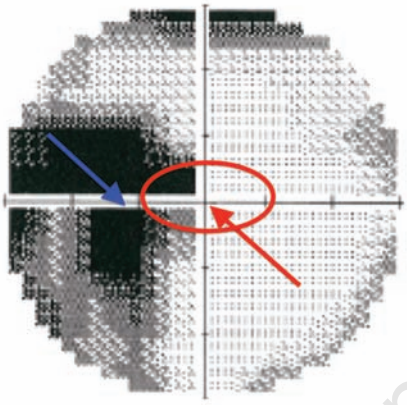

Figure 1. Humphrey visual field plot for a subject with macular disease.

Early microperimeters

The earliest report of fundus-specific perimetry was by Tantas in 1955, who performed manual perimetry by projecting a stimulus through a direct ophthalmoscope.[10] In the early 1970s, Awaya modified this technique using a visuscope[11] In 1976, Kani used a modified fundus camera to perform fundus-specific perimetry.[12]

The first commercially available device for fundus-specific perimetry described in the literature was the SLO-101 (Rodenstock GmbH, Munich, Germany).[13] This instrument used a 780 nm infrared laser that scans across the retina to produce a monochromatic image of the retina. A 633 nm Helium-Neon laser was used to present red stimuli at known retinal locations. The patient used a button press to report whether the target was seen.

This system was manual: the investigator chooses the intensity and retinal location of the stimulus using a mouse pointer. Once the target is presented, the retinal image is frozen and a retinal landmark is chosen by the investigator. At the end of the investigation, the positions of the retinal landmark are superimposed in each frame, and a map of seeing and non-seeing retina is created (Figure 3). This technique was time-consuming and required considerable training. Some laboratories wrote computer programs to automate some aspects of this process.[14]

Strengths of the SLO-101 included its bright target, high quality retinal image, and the ability to customize many aspects of the target if a suitably skilled computer programmer was available. However, this instrument was noisy, difficult to use and was limited to red stimuli. Furthermore, skilled programmers and technicians were required to perform any non-standard perimetry and to maintain the instrument. This machine is no longer commercially available.

The Nidek MP-1 microperimeter

The first next-generation microperimeter was the MP-1 microperimeter, launched in 2002 by Nidek Technologies of Italy. This system was first described in the literature by Nishida and colleagues.[15] The MP-1 microperimeter uses an infrared camera to create a retinal image, and stimuli are presented on an LCD screen within the instrument. This allows full color stimuli to be presented. Retinal tracking is performed automatically, although the investigator still needs to identify a suitable retinal area to track (with high-contrast retinal features such as blood vessels or pigment). A conventional fundus camera is used to take a full color image at the end of the assessment, and the visual field map is superimposed onto the retinal image (Figure 4).

The MP-1 microperimeter includes a variety of visual field patterns including a 10-2 grid, macular grids and patterns optimized for retinal or neurological field loss. Many aspects of the perimetry technique can be customized, including the position of each stimulus, the target size, the thresholding technique, and the fixation target. It can also perform kinetic perimetry, and can be used in a manual mode in which the investigator selects areas of the retina of particular interest to test. A follow-up mode allows longitudinal studies to be performed easily.[16] Test-retest variability of the MP-1 is relatively good in people with macular disease; Chen and colleagues found that mean sensitivity changed by an average of 0.2dB

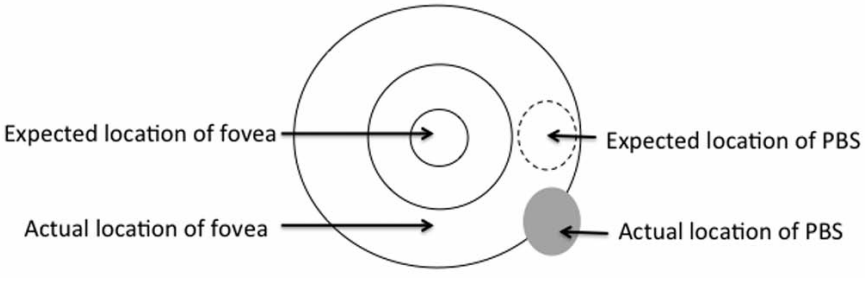

Figure 2. Calculating location of fovea from location of the physiological blind spot (PBS) corresponding to the optic nerve head.

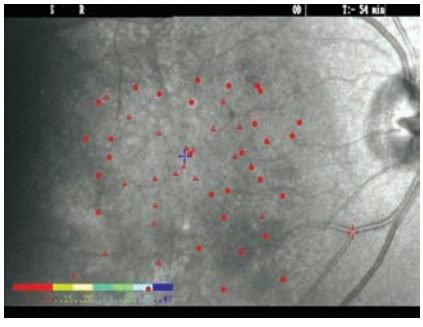

Figure 3. Scanning laser ophthalmoscope microperimetry plot. Red triangles show non-seen points, red circles show seen points. Blue cross shows fixation target. Red cross shows retinal landmark used for superimposing retinal images.

between two tests, although when looking at individual points the mean coefficient of repeatability was 5.5dB.[17]

Although the MP-1 has some advantages over the SLO-101, in particular being easier to use, there are several limitations. The infrared camera does not create as clear an image as the scanning laser based systems, and pupil dilation is required in many cases to create clear images. The stimulus is relatively dim: maximum target luminance is approximately 130cd/m^2. This compares unfavorably with the scanning laser ophthalmoscope (at least 200 cd/m^2) and the Humphrey perimeter (3,183 cd/m^2). Furthermore, the dynamic range of the screen is only 2 log units, meaning that the dimmest stimulus which can be presented is only 1% of the intensity of the brightest target. This limited range means that people with good vision reach a ceiling (where all of the targets can be seen at the dimmest intensity), and those with retinal disease may reach a floor (where none of the targets are seen even at maximum brightness).

Acton and colleague recently calculated the sensitivity range of the MP-1 microperimeter and related it to values for the Humphrey perimeter. They determined that a value of 0dB on the MP-1 is equivalent to 14dB on the Humphrey, and that 0dB on the MP-1 is equivalent to 34dB on the Humphrey field analyzer.[18]

The OCT-SLO

The OCT-SLO (OPKO, Miami, FL, USA) is a device that combines a spectral optical coherence tomographer (OCT) with a scanning laser ophthalmoscope-based microperimeter. Since the optical pathways of the two imaging modes are coherent, the machine allows precise registration of the SLO fundus image with the OCT structural image. In addition, the OCT-SLO screen projects targets through the same optics. The maximum stimulus intensity of the OCT-SLO is approximately the same as the MP-1 at 137cd/m^2. The dynamic range of stimulus presentation is also 2 log units. The nominal intensities of the OCT-SLO perimetry stimuli are 0 to 20 dB, which is roughly equivalent to 14 to 34 dB on the Humphrey Field Analyzer. A variety of set stimulus arrays and thresholding algorithms are available, as is a manual mode. Figure 5 shows an example visual field plot from the OCT-SLO. Since the OCT-SLO uses an SLO to image the fundus, pupil dilation is not necessary and a clearer retinal image is available for retinal tracking during perimetry.

The primary advantage of the OPKO instrument is its multiple imaging modalities. Direct structure/function comparisons can be made by imaging the retina underlying each microperimetry point. In addition, the PRL can be quantified by relating its position to the anatomic fovea. The OCT also allows function to be correlated to retinal thickness and the presence of edema, subretinal fluid or drusen, and to be directly related to the integrity of the photoreceptor layer.[19]

The MAIA microperimeter

A final option for performing microperimetry is the Macular Integrity Assessment or MAIA microperimeter (CenterVue, Padova, Italy). This microperimeter uses a scanning laser to perform retinal imaging and an LED light as a stimulus. As with the OCT/SLO perimeter, the retinal image quality is very high and pupil dilation is rarely required. The MAIA has fewer options which can be customized: only two fixation targets and five grid patterns are available. Stimuli can only be presented within the central 20° which removes the problem of distortion of non-central targets reported on the MP-1 microperimeter.[20] A significant advantage of the MAIA microperimeter is its higher maximum target intensity (318 cd/m^2; equivalent to 10dB on the Humphrey field analyzer) and the better dynamic range of the stimulus (3.6 log units) (Marco Morales, Centervue Inc., personal communication, 2011). Figure 6 shows an image from the MAIA microperimeter.

Although the MAIA microperimeter has not yet been used widely in research, an interesting recent publication describes the use of this instrument alongside classical music for visual rehabilitation training.[21]

Different users have expressed different preferences for which device to use with patients with low vision. Retinal images from the OCT/SLO and MAIA are superior to those of the MP-1 that enables easier eyetracking without the need for pupil dilation. This is extremely useful for low vision clinicians and others who need to assess reading following a microperimetry assessment. Each clinician will have their own preferences about which instrument is easiest to use and the most useful.

The use of microperimetry

The growth of papers relating to microperimetry in recent years reflects its increasing use in clinical trials, research projects and in clinical practice (Figure 7). In particular, the development of the MP-1 microperimeter has coincided with a significant increase of interest in fundus related perimetry. Although most reports of microperimetry describe people with central visual field loss from age-related macular disease, these instruments have also been used to measure visual fields in people with Stargardt disease,[22] macular hole,[23] macular telangiectasia,[24] macular

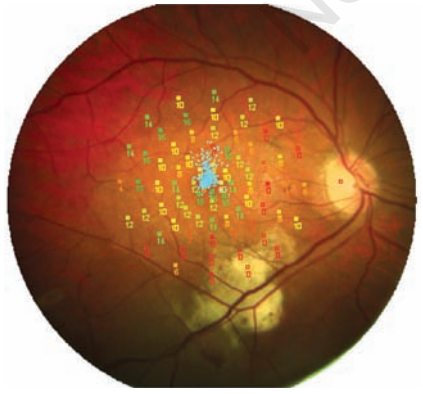

Figure 4. Example microperimetry plot from the MP-1 microperimeter.

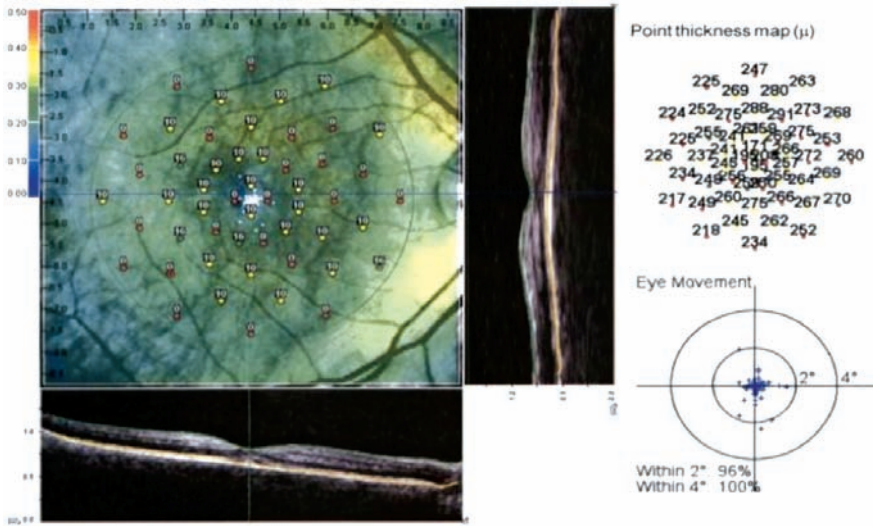

Figure 5. Microperimetry plot and OCT data from the OPKO microperimeter.

edema,[25] glaucoma,[26] central serous chorioretinopathy,[27] and diabetic retinopathy.[28]

The *follow-up* mode available on many microperimeters allows them to be used for longitudinal monitoring. It has been suggested that this feature is used to monitor the progression of conditions such as retinal vein occlusion,[29] and to determine the effect of lutein supplementation in people at risk of age-related macular degeneration.[30]

In optometric practice, the most common indications for using microperimetry will be in the assessment of people with macular disease and in low vision rehabilitation. Microperimetry can identify the location of fixation (the *preferred retinal locus*) of people with central visual field loss and can be used as an adjunct to training optimal fixation behaviour in people with macular disease.

Microperimetry is also useful in people with suspected neurological field loss who also have macular disease. As conventional perimetry does not correct for poor fixation stability, homonymous defects or those respecting the vertical midline may not be obvious using conventional perimetry.

Conclusions

Fundus related microperimetry is the only reliable way to perform visual field assessment in people with non-central or unstable fixation due to macular disease. This technique is increasingly used in clinical trials, clinical research and clinical practice. It will be of particular benefit in detecting other pathologies in people with central field loss; for example, neurological or glaucomatous field loss may not be detected in people with very poor fixation and unreliable conventional visual fields. A variety of different instruments are currently available for microperimetry, all of which have relative strengths and weaknesses. It is hoped that future microperimeters will overcome some of the limitations of currently available devices.

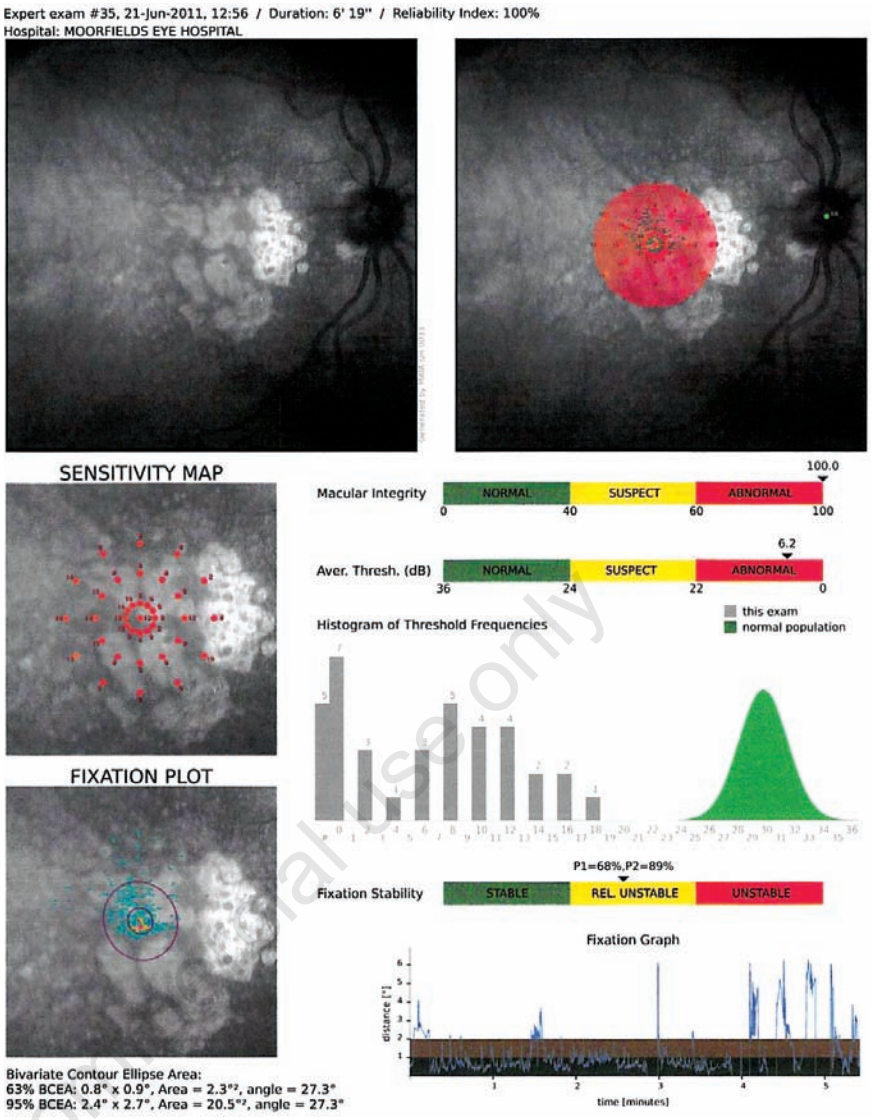

Figure 6. Example microperimetry plot from the MAIA microperimeter.

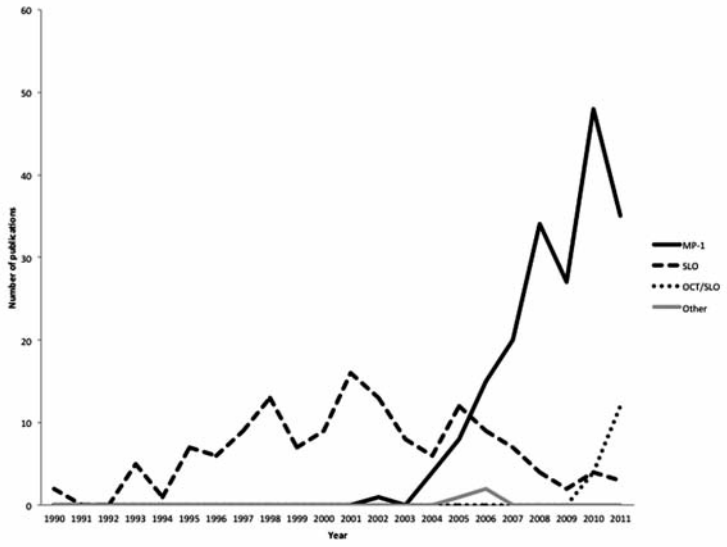

Figure 7. Number of papers using various types of microperimetry, January 1990-August 2011. NB: only eight months of data are included for 2011.

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