An Automated Measuring System for Fundus Perimetry

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Purpose: In order to automate fundus perimetry, which is usually laborious because of the many manual operations and the frequent eye movements, we developed a new fundus perimeter with an automated measuring system using computer technology.

Methods: This fundus perimeter consists of an infrared fundus camera, a fundus-pursuit unit, and a target-display unit. Both units are personal computers operating on Windows™. After presetting the measuring points on the fundus, perimetry is automatically performed. The fundus-pursuit unit recognizes and pursues the fundus reference region while calculating its coordinates in real time during perimetry. The target-display unit corrects the stimulus coordinates with data from the fundus-pursuit unit and even if eye movement occurs, automatically displays the stimulus targets at the correct retinal point that had been preset.

Results: Fundus perimetry can be automatically and precisely performed with this automated measuring system. It shortens the duration of the examination and frees the operator from the lengthy and laborious manual operations during perimetry.

Conclusions: This automated measuring system will make fundus perimetry easier for the operator, as well as more popular for clinical use. **Jpn J Ophthalmol 2002;46:627–633** © 2002 Japanese Ophthalmological Society

Key Words: Automated system, eye movement, fundus perimeter, fundus perimetry.

Introduction

Fundus perimetry is the most appropriate method for measuring retinal sensitivity because it is possible to monitor the fundus region where the stimulus target is presented. Therefore, in fundus perimetry the retinal sensitivity accurately corresponds to even small retinal lesions. On the other hand, in ordinary perimetry, sensitivity does not accurately correspond with lesions even when the results are overlaid on the fundus image. Unless the fundus is monitored, there is no guarantee that a stimulus is accurately located on a selective fundus region because the fundus is unstable due to eye movements during examination.

More than 20 years ago, we developed one of the first fundus perimeters.[1,2] The examiners can precisely place a stimulus at any point that they want to measure, monitoring the fundus. Even in a small retinal lesion, detailed profiles of retinal sensitivity can be obtained. However, the measurements are not so easy because laborious manual operations have to be performed. Moreover, frequent fundus shifts due to eye movement make fundus perimetry difficult. Therefore, this examination is time-consuming, and its reproducibility is often decreased due to the subject's fatigue and confusion. On the other hand, the ordinary automated perimeter made perimetry much easier because many stimuli can be automatically presented without any manual operations and the examination time can be reduced.

In order to make fundus perimetry easier and more popular, it is necessary to develop an automated system, like that in the ordinary perimetry. However, when the fundus perimetry is automated, it is necessary not only to automatically present the stimuli, but also to control the fundus shifts due to eye movements during the examination. Otherwise it is impossible to present stimuli at correct retinal points preset before the examination, and the results would not be at all reliable. In order to resolve these

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problems for clinical use, we developed a new fundus perimeter with an automated measuring system. This automated measuring system has made the following possible. First, many stimulus points can be preset on the fundus before the examination, and stimulus targets can be automatically displayed during perimetry. Second, coordinates of preset stimulus points can be automatically corrected in real time, even if fundus shifts due to eye movements occur.

In the present paper, we will explain the new fundus perimeter with the automated measuring system and the possibility that fundus perimetry will be automated in the future.

Materials and Methods

Instruments

The perimeter consists of three components; an infrared fundus camera (TRC-50IA; Topcon, Tokyo), a fundus-pursuit unit, and a target-display unit, as shown in Figure 1. The CCD camera (Hitachi, Tokyo) and the liquid crystal color monitor (LMD-1040XC; Sony, Tokyo) are attached to the infrared fundus camera. The fundus-pursuit and the target-display units are computers operating on Windows NT™. An image processing board (Genesis; Matrox, Dorval, Quebec, Canada) is set up in the fundus-pursuit unit. Electrical cables connect the CCD camera and the fundus-pursuit unit, the fundus-pursuit unit and the target-display unit, and the target-display unit and the liquid crystal monitor.

Signal Relays During Perimetry

The fundus image of the subject is taken by the CCD camera via a dichroic mirror, as shown in Figure 1. The signals of the fundus images are transferred from the CCD camera to the fundus-pursuit unit. The fundus-pursuit unit, in which the image processing board is mounted, recognizes the image pattern of the reference fundus region, pursues the reference region that frequently shifts due to eye movements, and calculates its coordinates in real time, as shown in Figure 2. The fundus-pursuit unit transmits the signals of the coordinate data to the target-display unit. The target-display unit corrects the coordinates of the stimulus point with the data from the fundus-pursuit unit even when eye move-

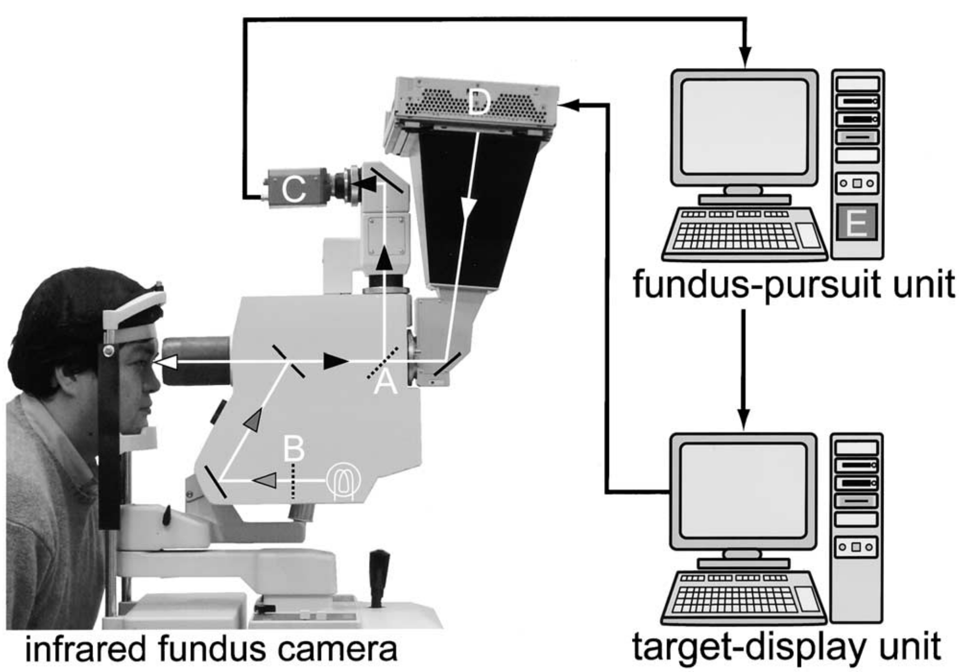

Figure 1. A block diagram shows the three components (ie, infrared fundus camera, fundus-pursuit unit, and target-display unit) of the fundus perimeter and the signal relays during perimetry. A: a dichroic mirror, B: the infrared filter (IR82; Fuji Film, Japan), C: the CCD camera, D: the liquid crystal color monitor, E: the image processing board mounted in the fundus-pursuit unit. The signals are transmitted from the infrared fundus camera to the target-display unit, via the fundus pursuit unit. The target automatically displayed in the liquid crystal monitor stimulates the correct retinal point. The dichroic mirror divides the optical system into that of the fundus image (shown by black arrowheads) and that of the stimulus target (shown by white arrowheads). Consequently, both optical systems are conjugated.

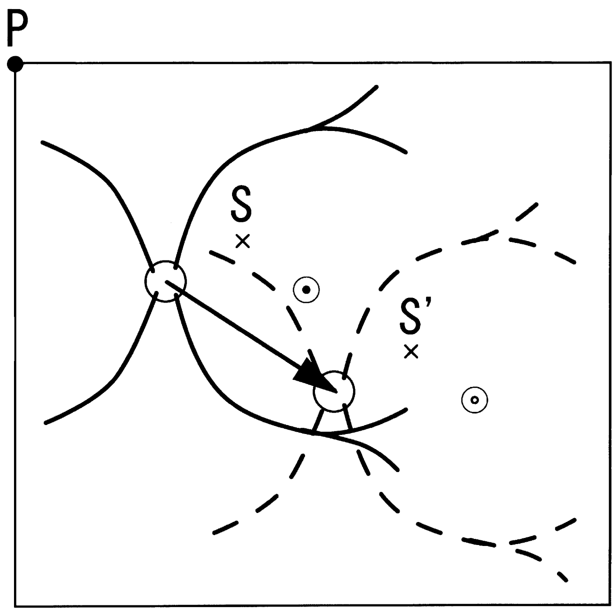

Figure 2. When a fundus shift occurs within the coordinates (P) due to eye movement, the change in coordinate values is calculated by the fundus pursuit unit. Then the target-display unit corrects the coordinates of the stimulus point, from S to S′, with the data from the fundus-pursuit unit.

ment occurs. When the target-display unit displays the stimulus target in the liquid crystal monitor, the target stimulates the corrected retinal point that was preset before perimetry.

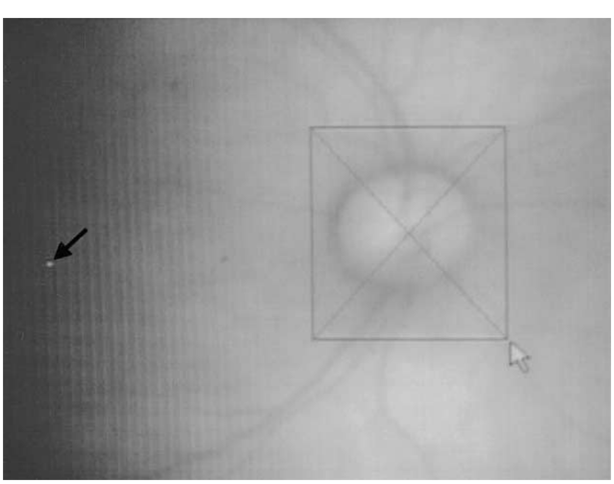

Figure 3. The reference region is enclosed in a rectangle by moving the white arrow cursor. Because the optic disc has a high contrast in this image, it is an adequate reference. A white dot (indicated by a black arrow) is the fixation target.

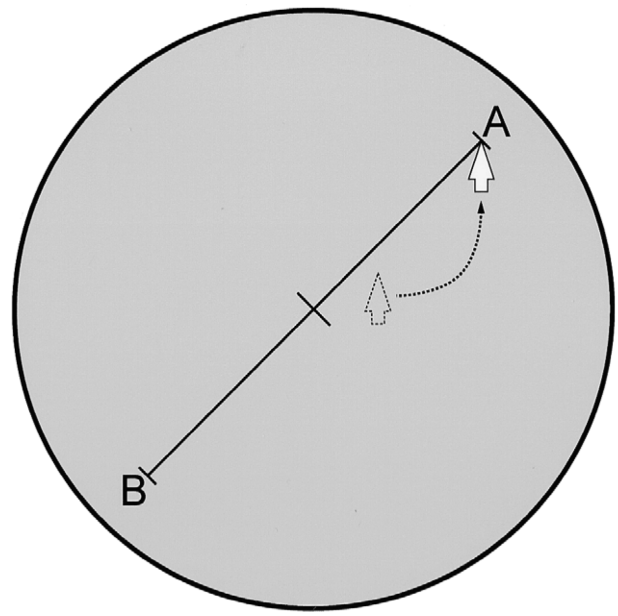

Figure 4. Matching coordinates of fundus image to those of stimulus target. After attaching a cylinder with a scale to the fundus camera, the examiner views a tilted scale and a cursor. The ends of the scale (shown as A and B) are reference points for matching both coordinates. A cursor (shown as an arrow) displayed in the liquid crystal monitor is moved by the mouse of the fundus-pursuit and the target-display unit. When the examiner points at the reference region with the cursor, he clicks the mouse of the fundus-pursuit unit and then the mouse of the target-display unit. The common coordinates are thereby registered in both units.

Actual Procedures

The actual procedure is as follows. First, one of three fixation targets is selected: a single dot, a cross, or four dots in a square pattern. When the subject fixates on the target and stabilizes the fundus image, the fundus image from the camera is captured in the fundus-pursuit unit. The reference region is indicated by enclosing it with the cursor on the captured fundus image (Figure 3), so that the fundus-pursuit unit can recognize the image pattern of the reference region and pursue it. The optic disc is the optimal region for reference because its contrast is the highest in the infrared fundus image. The measuring points are preset in the captured fundus image. They can be set not only manually, but also by using stimulus templates (grid or radial pattern). In the stimulus templates, the distance between stimulus points and the number of the points can be optionally chosen. The picture angle of the fundus camera is 50° in diameter and the measurement area of perimetry is 35° (horizontally) × 25° (vertically). The luminance of

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the stimulus targets is optionally changed from 4 to 104 apostilb (dynamic range; 14 dB). By changing the value in red, green, and blue of the liquid crystal monitor, colored stimuli can be presented. The luminance of the background is 4 apostilb. Finally, size, intensity, duration, and interval of stimuli are decided. After the examination begins, the stimulus targets are automatically and precisely displayed at the correct retinal points without any manual operations. The fundus-pursuit unit pursues the reference region, calculating the fundus coordinates, and the target-display unit corrects the coordinates of the stimulus point in real time. The sampling rate for calculating the fundus coordinates is 20 times per second. The stimulus target is randomly displayed at each point. The subject responds by means of clicking a mouse when he sees the stimulus target, and the responses are recorded. After the examination, the results are presented as symbols or colored dots at the stimulus points on the captured fundus image. Other fundus images (eg, color photograph, fluorescein angiograph, etc.) can be overlaid onto the infrared one, when the two or three reference points (eg, the bifurcation of the retinal vessel) correspond in both images. Moreover, the data of the fundus shifts during perimetry can be recorded as coordinate values.

Matching Coordinates of Fundus Image to Those of Stimulus Target

As shown in Figure 1, there are two optical systems in the infrared fundus camera, one for the fundus image and the other for the stimulus target. In order to match the coordinates of the fundus image to those of the stimulus target before perimetry, a cylinder with a scale is attached in front of the objective lens of the fundus camera. The scale line is tilted to 45°. The ends of the scale are reference points for matching the coordinates. The cursor of the fundus-pursuit or the target-display unit is displayed in the liquid crystal monitor. The examiner views the reference points in the tilted scale and the cursor in the liquid crystal monitor (Figure 4). The mouse of both the fundus-pursuit and the target-display units is clicked after the cursor is pointed at the reference points. Then the coordinates of the reference points are registered in both units. Consequently, both units have a common coordinate system, and coordinates of both the fundus image and the stimulus target can be matched.

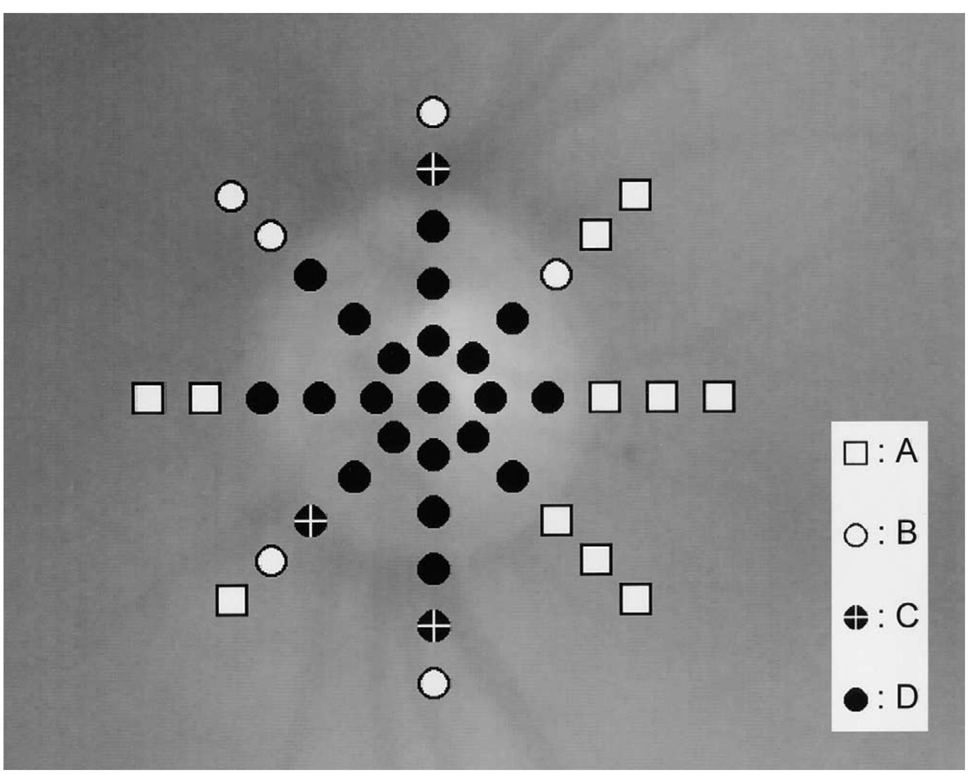

Figure 5. The scotoma corresponds to the optic disc shape. A: ability of the patient to see a target of 3 minutes of arc in diameter, B: 9 minutes, C: 15 minutes, D: target is still invisible at 15 minutes. Note that the symbol size is not the same as the actual stimulus target size, but larger.

Results

Three representative subjects who were examined with our fundus perimeter are described below. All subjects in our fundus perimetry examinations gave their informed consent. In the stimulus condition, the luminance of the stimulus was 104 apostilb. The duration was 0.1 second, and the interval was 1.9 seconds. The target size was 3, 9, or 15 minutes of arc in diameter.

Using a radial stimulus template, we measured a physiological scotoma correspondent with an optic disc in a normal 29-year-old man whose corrected visual acuity was 1.5. In Figure 5, no sensitivity was shown within the optic disc, and the scotomatous pattern precisely corresponds to the shape of the optic disc.

The fundus in a patient with upper hemi-retinal artery occlusion in the right eye is shown in Figure 6. The patient was 72 years old and his corrected visual acuity was 0.6. The results of fundus perimetry were overlaid on the color fundus photograph. Retinal edema due to circulatory insufficiency is observed in the upper portion of the fundus and is horizontally bordered. The grid-pattern stimuli were used in this case. Reflecting retinal circulation, the distribution of retinal sensitivity is divided into the regions where retinal sensitivity is good in the lower, or decreased in the upper. Because the number of stimuli was 50 in each sequence, it took 100 seconds for each sequence in both subjects. The total examination time for 1 patient was only about 5 minutes.

In Figure 7, the fundus in a patient with macular hole in the left eye is shown. She was 66 years old and her visual acuity was 0.1. Her fixation point was located on the nasal upper margin around the macular hole. The radial stimulus template was used in the fundus perimetry. In the macular hole, there is no retinal sensitivity. The pattern of these retinal sensitivities reflects the shape of the retinal lesion very well. Even a small scotoma such as a macular hole could be automatically detected when employing the automated measuring system.

Discussion

Our perimeter with the automated measuring system makes fundus perimetry almost fully automated and makes it possible to detect a scotoma even in the macular hole. The motivation for its development was provided by our previous experiences[1,2] with fundus perimetry. The problems that we previously encountered were as follows. First, it was laborious to aim manually at each stimulus point. Second, when eye movement frequently occurred in subjects, especially those with low visual acuity, it was very

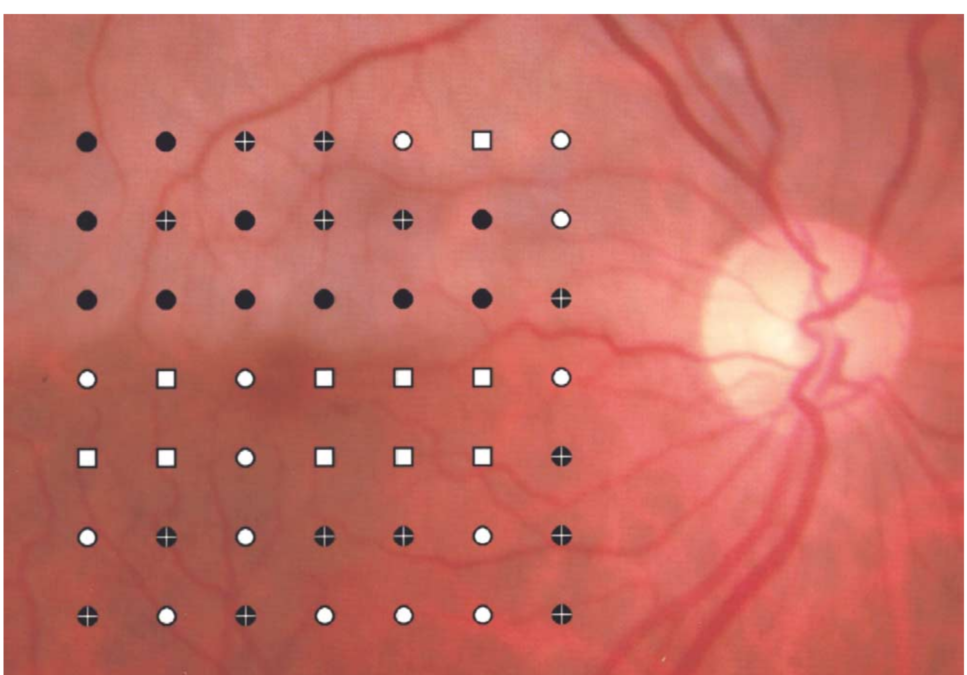

Figure 6. The retinal sensitivity of a patient with hemi-retinal artery occlusion in the right eye. The sensitivity was shown using the same criteria as in Figure 3. The figure was made by overlaying the color fundus image on the infrared image.

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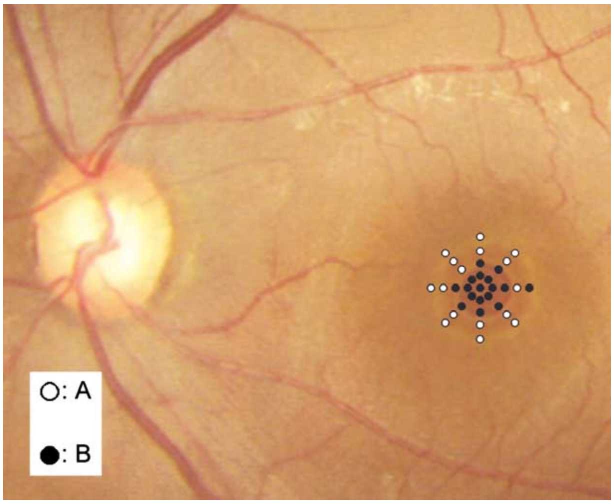

Figure 7. The retinal sensitivity of a patient with a macular hole in the left eye. A: the ability of the patient to see a target of 15 minutes of arc in diameter, B: target is invisible.

difficult to precisely stimulate the desired retinal point due to the instability of their fixation. Consequently, there was no guarantee that the stimulus could be accurately repeated at the same point. These problems discouraged both clinicians and subjects from applying this useful perimetry, in spite of its long history.[1–6] Previously, we had the experience of applying the overlay technique to the fundus image[7] using computer technology. It makes it possible for the reference fundus image to be shifted and matched to the search area of the input fundus image. Therefore, fundus shifts due to eye movement could be calculated. A few years ago, we developed a prototype system[8] that could control the adjustment of a stimulus point even if eye movement occurred. Finally, we have developed this new automated fundus perimeter by combining a stimulus-display system with a coordinate-adjustment system.

Recently, "landmark-driven fundus perimetry" employing the scanning laser ophthalmoscope[9] (SLO) was developed by Sunnes et al.[10] It also makes it possible to preplan stimulus points before examination and to measure at the correct retinal point even if eye movements occur. Although this method also made it possible to increase the accuracy of stimulus location, it is necessary to point manually at a fundus landmark for each stimulus. Therefore, the interval between stimuli depends upon the operator's skill. On the other hand, the interval in our instrument is constant and short because stimuli are displayed automatically. Consequently, it is likely that our device will shorten the duration of the examination, and reduce the burden on the subjects. In addition, with our new automated fundus perimeter the stimuli at the same retinal points can be automatically repeated in other sequences. Moreover, our perimeter makes it possible to precisely evaluate fixation stability[11–13] in subjects because fundus shifts of data during the examination can be simultaneously recorded in the computer.

We employed an infrared fundus camera in our fundus perimeter because our previous experience[1,2] made the development of the automated system easier. The quality of infrared fundus images was improved by the use of a CCD camera, although it is evident that SLO has much better image quality than an infrared fundus camera. The overlay of another fundus image also compensates for the disadvantages in image quality.

Even with our perimeter with an automated measuring system, it is impossible to accurately stimulate the retinal point when large eye movements or blinking occurs. In the near future, we will resolve this problem with a system that resumes measurement after it is temporarily interrupted by large eye movements or blinking.

In conclusion, the automated system in our perimeter presents the possibility that fundus perimetry will become automated, clinically easier, and more popular in the near future.

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