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CLINICAL INVESTIGATION

Evaluation of kinetic programs in various automated perimeters

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Abstract
Purpose Kinetic programs in four automated perimeters were evaluated and compared for their clinical usefulness using four simulated visual field (VF) patterns.
Methods Using the results of conventional Goldmann manual kinetic perimetry (MKP), simulated fields with concentric contraction, a temporal residual island only, a small central island with a temporal island, and a ring scotoma were created. Four kinetic programs, Humphrey 750i Kinetic Test (Humphrey), OCULUS Twinfield 2 Kinetic Perimetry (OCULUS), OCTOPUS 900 Goldmann Kinetic Perimetry (OCTOPUS GKP), and Kowa AP-7000 Isopter (Kowa) were tested by the 4 simulated defect patterns using stimuli of V/4e, I/4e, I/3e, I/2e, and I/1e at speeds of 3 and 5°/s.
Results Except Humphrey, OCULUS, OCTOPUS GKP, and Kowa could obtain isopters nearly comparable to those of Goldmann MKP. However, their results were considerably influenced by the examiner's skill. Besides, Humphrey had restrictions on target presentation, and OCULUS and Kowa had problems in isopter drawing and in filling in the scotoma. OCTOPUS GKP was the only method that could correctly detect and depict all four defect patterns. It also had relatively shorter test durations among the three methods excluding Humphrey, which did not have a built-in function for test duration measurement. The perimeters' test ranges for the periphery were 90° for Humphrey, OCULUS, and OCTOPUS GKP, and 80° for Kowa.
Conclusion To assess kinetic fields with various defect patterns, OCTOPUS GKP seems to be the most useful method.

Keywords Automated kinetic perimetry · Humphrey 750i Kinetic Test · OCULUS Twinfield 2 Kinetic Perimetry · OCTOPUS 900 Goldmann Kinetic Perimetry · Kowa AP-7000 Isopter

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Introduction

There are two methods to evaluate the visual field (VF) in perimetry, kinetic and static. In kinetic perimetry, target size and luminance are fixed and the target is moved to determine an isopter. In static perimetry the target is fixed at a determined test point and the luminance is changed to measure the visibility at each test point [1]. Currently, static perimetry is the mainstream due to the spread of automated perimeters and has gained more popularity than kinetic perimetry for a few practical reasons. Because static perimetry is usually used to evaluate the central 30° of the VF, the test duration is significantly shortened. This is clinically useful as it is difficult to measure the entire VF within a limited test duration. Moreover, sensitivity results fluctuate more in the peripheral VF than in the central 30° and thus, test results by static perimetry are more reliable than by a kinetic method.

On the other hand, kinetic perimetry remains an important method to evaluate the VF in patients with advanced glaucoma, retinal diseases, and other optic neuropathy [2, 3]. Manual kinetic perimetry (MKP) using a Goldmann perimeter [4] is widely used owing to its capability in measuring the entire VF, including the periphery and center, in a relatively shorter duration. With

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Goldmann MKP, the VF can be diagnosed at a glance in its entirety. However, Goldmann MKP has many disadvantages including examiner bias, intra-examiner differences in choosing stimulus velocity [5], and lack of standardization, autocalibration, and permanent documentation of test procedures and results. Automated kinetic perimetry can help minimize problems related to perimetric technique and thus reduces examiner bias [6–11]. Starting with the revolutionary Fieldmaster 5000 [12–15] and Perimetron [16, 17], various types of automated kinetic perimeters have been developed and several have become commercially available. At the same time, Goldmann MKP is still the standard kinetic method [4].

To find an automated kinetic method that has advantages over MKP and produces results comparable to those of Goldmann MKP, we evaluated the clinical usefulness of the following four extant kinetic programs in automated perimeters: (1) Humphrey 750i Kinetic Test (Humphrey; Carl Zeiss Meditec, Dublin, CA, USA) [18, 19], (2) OCULUS Twinfield 2 Kinetic Perimetry (OCULUS; Oculus Inc., Wetzlar, Germany) [11], (3) OCTOPUS 900 Goldmann Kinetic Perimetry (OCTOPUS GKP; Haag-Streit Inc., Koeniz, Switzerland) [6–10], and (4) Kowa AP-7000 Isopter (Kowa Inc., Nagoya, Japan) [20]. To test these four methods, four different VF defect patterns (concentric contraction, a temporal residual island only, a small central island with a temporal island, and a ring scotoma) were created and the test results, range, and duration of the four methods were compared. To our knowledge, no such comparison and evaluation have been made previously.

Materials and methods

Using previous test results of conventional Goldmann MKP, we created four virtual VF patterns: concentric contraction (Fig. 1a), a temporal residual island of vision only (Fig. 1b), a small central island with a temporal island (Fig. 1c), and a ring scotoma (Fig. 1d). The patterns were made using shading filters and were fixed on an eye cup made of clear plastic material (Fig. 2a, b). We first mapped the Goldmann MKP test results of the eye cup by matching the visual angles in the temporal, nasal, superior and inferior fields. Using the filter, a defect pattern of the shape and size of the defect depicted by Goldmann MKP was then cut out and attached to the eye cup. The shading filters used Zero Black Film (Mirareed Corporation, Tokyo, Japan) with 0.004% light transmission; the examinee could not perceive any stimulus through this film. The subject of this study was a healthy 30-year-old woman volunteer with visual acuity of 20/20 who had previous experience with kinetic perimetry. The subject put on the eye cup to test the 4 perimeters with each of the 4 VF patterns in turn, a total of 16 tests. An opaque occluder covered the untested eye during the perimetric test. All the examinations were performed by the same examiner (SH).

The four commercially-available kinetic programs tested in this study were Humphrey (Carl Zeiss Meditec), OCULUS (OCULUS Optikgeräte) OCTOPUS GKP (Haag Streit AG), and Kowa (Kowa Inc.). Acoding to the manufacturers' specifications, the 4 perimeters have similar specifications except the maximum luminance (Humphrey, 3183 cd/m^2; OCULUS, 318 cd/m^2; OCTOPUS GKP, 1910 cd/m^2; and Kowa, 3183 cd/m^2). The background luminance is 10 cd/m^2 for all 4 programs. While Humphrey and Kowa have built-in kinetic software, the hemispherical bowls of OCTOPUS and OCULUS are connected to and controlled by separated external personal computers with the perimeters' own kinetic software. All four kinetic programs have both semi-automated and fully-automated testing options. In fully-automated testing, stimuli are automatically moved along fixed meridians determined before the test. The examiner cannot add isopters in real time even if abnormalities are found in some areas of the VF. The program also automatically depicts the final isopter. In semi-automated testing, the examiner has to determine the initial/end points and direction of the vectors, manually connect all the response points on the computer screen to depict an isopter, and add additional vectors if necessary. To obtain more detailed test results for better comparison, we only used the semi-automated testing option in the four programs.

In this study, 5 stimuli (V/4e, I/4e, I/3e, I/2e, and I/1e) were used to assess the VF loss. Stimulus speeds of 3 and 5°/s were, respectively, used within and beyond 30° eccentricity [4]. At a constant stimulus speed, stimuli of a selected size and at a luminance level according to the Goldmann classification [4] were generated by the kinetic programs. The generated stimuli were continously moved from nonvisible areas towards visible areas of the VF along user-defined vectors that were drawn manually by the examiner with a computer mouse or an electronic pen directly on the computer touch screen either before or during the perimetric test. During perimetry, the examiner had to select the initial and end points, direction, and length of the vectors for the three methods excluding Humphrey. In the Humphrey program, the end point is always fixed at (x, y) = (0,0) and thus, the examiner only needs to select the initial point. The stimulus movement along each vector was terminated by the response of the subject, who was instructed to look straight ahead at the fixation point and to press the response button as soon as the stimulus was perceived. Upon the subject's response, the stimulus location was automatically marked on the screen and finally, the examiner manually connected all the response points on the computer screen to depict an isopter. Vectors

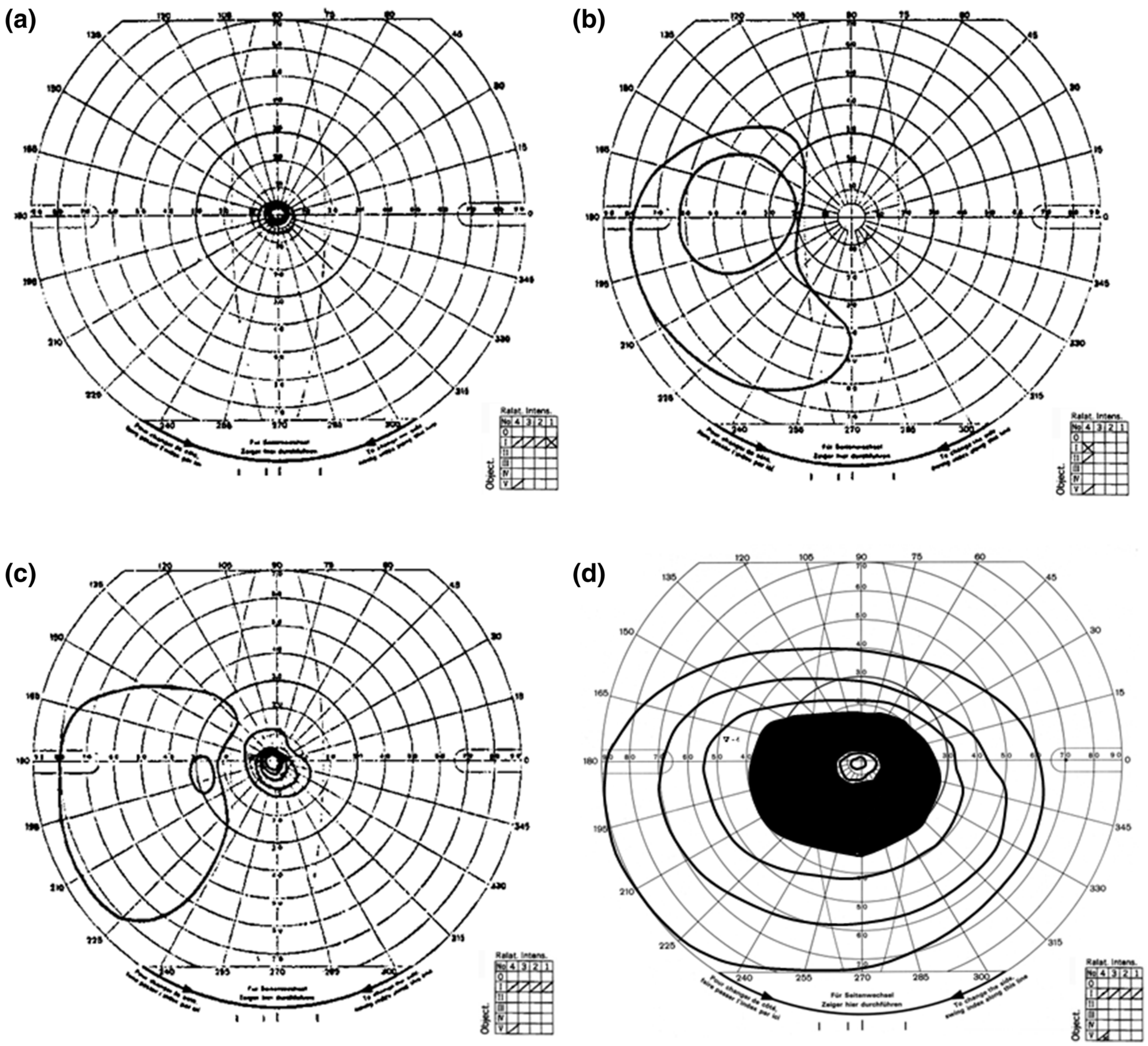
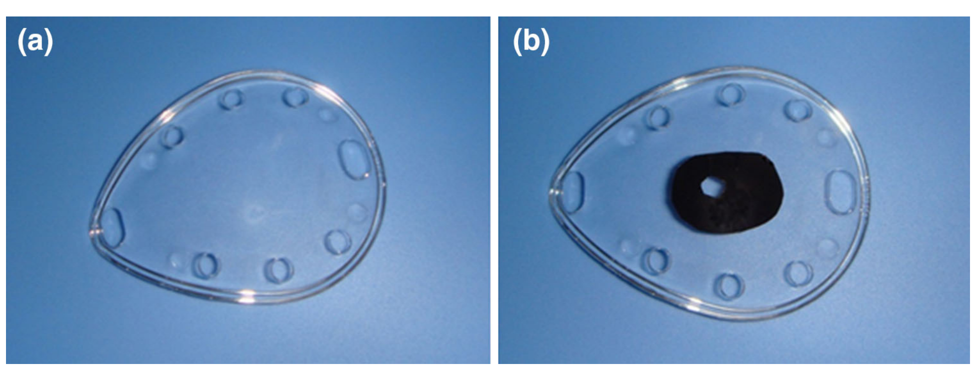


Fig. 1 Results of conventional Goldmann MKP for the four VF patterns. **a** Concentric contraction. **b** A temporal residual island only. **c** A small central island with a temporal island. **d** A ring scotoma

Fig. 2 **a** Eye cup. **b** Eye cup with shading filter



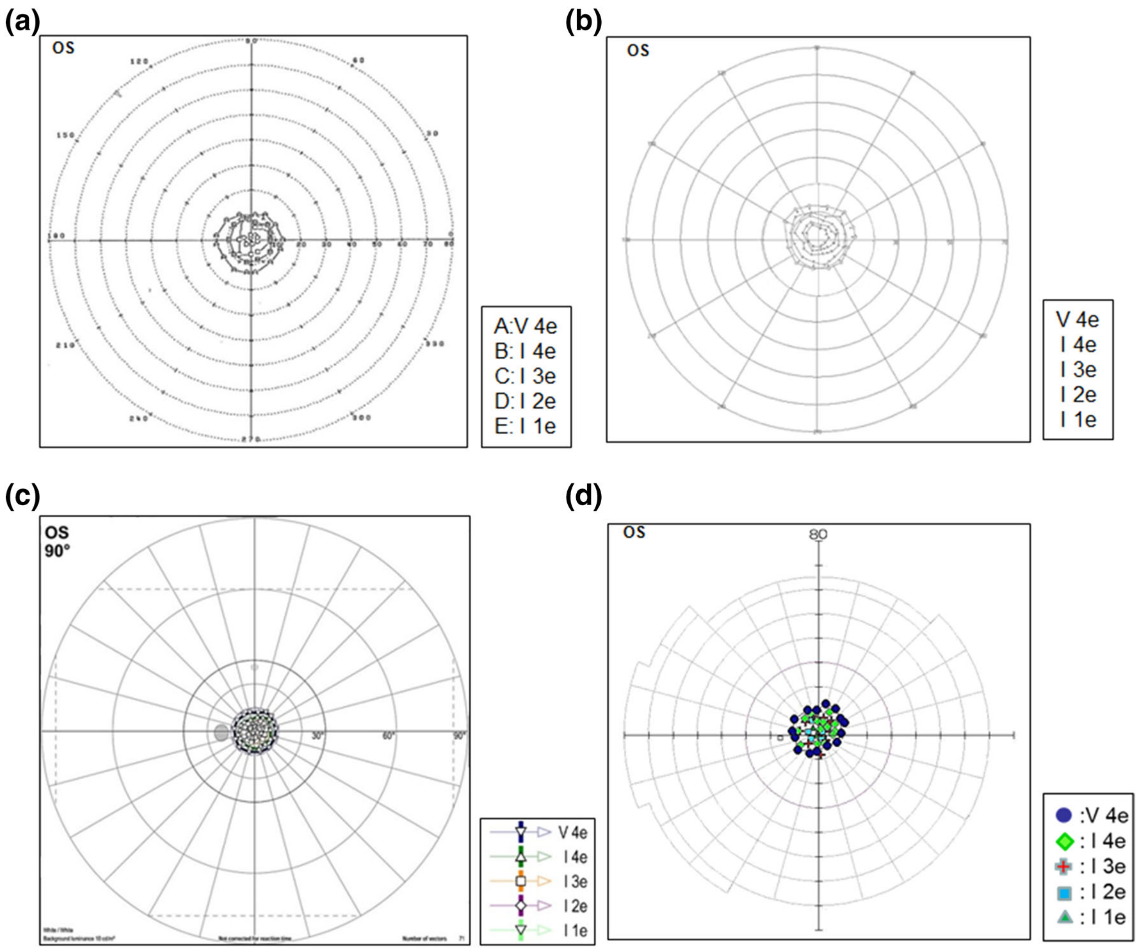


Fig. 3 Results for the pattern with concentric contraction. **a** Humphrey. **b** OCULUS. **c** OCTOPUS GKP. **d** Kowa. The four results for this pattern were close equivalents

were presented about 20° apart in a random order from the periphery towards the central field, and additional vectors were manually added by the examiner to the areas indicating abnormality depending on the depth and shape of the VF pattern. In a scotoma, the stimulus was presented inside the region of the field loss and moved outwards until the stimulus was perceived to determine the border of the scotoma. In this study, the subject's fixation was monitored by a video camera, except for OCTOPUS which has a built-in fixation monitoring mode. Test duration was automatically measured in the three programs excluding Humphrey, which did not have a built-in function for measuring test duration. Test duration in these semi-automated programs included the time for the examiner to select the initial/end points, direction, and length of vectors. Test results were automatically digitalized and recorded in the four programs.

This study protocol was approved by the Ethics Committee of Kindai University Faculty of Medicine and all the experiments were performed in accordance with the Declaration of Helsinki. Informed consent was obtained from the subject.

Results

Figure 3 shows the results of the 4 kinetic programs for concentric contraction and all 4 methods could obtain results comparable to the result by Goldmann MKP. The recorded test durations, except for Humphrey, were 8.58 min. (OCULUS), 4.35 min. (OCTOPUS GKP), and 9.31 min.s (Kowa). OCTOPUS GKP had a considerably shorter test dutration than the other two methods. Figure 4 shows the results for the VF with a temporal residual island only. Humphrey depicted an incomplete isopter with the joined temporal residual island and central point (Fig. 4a). The results of the other three methods were comparable to the Goldmann MKP result. The recorded test durations were 7.51 min. (OCULUS), 7.95 min. (OCTOPUS GKP), and 6.90 min. (Kowa). Figure 5 shows the results for a

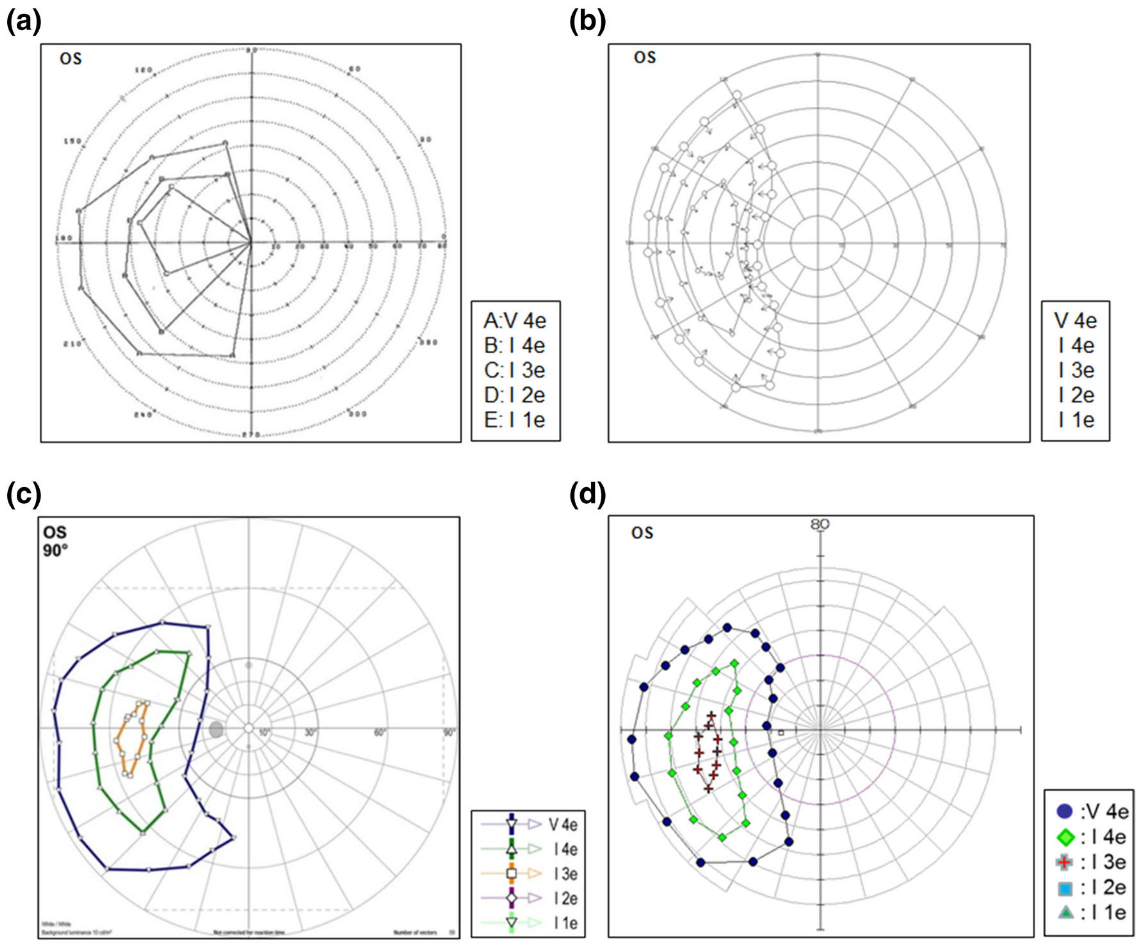


Fig. 4 Results for the pattern with a temporal residual island only. **a** Humphrey. **b** OCULUS. **c** OCTOPUS GKP. **d** Kowa. All methods except Humphrey correctly detected the VF pattern

small central island with a temporal island. While Humphrey (Fig. 5a) and OCULUS (Fig. 5b) depicted isopters with the joined small central island and temporal island, the other two methods could depict isopters comparable with the Goldmann MKP result. The recorded test durations were 13.48 min. (OCULUS), 9.33 min. (OCTOPUS GKP), and 13.21 min. (Kowa). Figure 6 shows the results for a ring scotoma and the 4 methods clearly varied in result with this defect pattern. While Humphrey (Fig. 6a) could not detect the pattern of the ring scotoma, OCULUS could detect the ring scotoma pattern but did not have the software for filling in the scotoma. Kowa could depict the ring scotoma pattern and fill in the scotoma, but it failed to fill in only the ring pattern. OCTOPUS GKP was the only method that could detect and successfully fill in the correct pattern of the ring scotoma, comparable to the results of Goldmann MKP. The recorded test durations were 13.9 min. (OCULUS), 8.00 min. (OCTOPUS GKP), and 18.87 min. (Kowa), and again, OCTOPUS GKP had a considerably shorter test duration than the other 2 methods. The test ranges for the peripheral field were 90° for Humphrey, OCULUS and OCTOPUS GKP, and 80° for Kowa.

Discussion

Four commercially available kinetic programs, Humphrey, OCULUS, OCTOPUS GKP, and Kowa were tested in this study and the OCTOPUS GKP appeared to be the most clinically useful.

To ensure comparability, all four kinetic programs were tested on the same VF defect patterns with different levels of difficulty. In concentric contraction, the results of the four progams were close equivalents (Fig. 3). Compared to the other three defect patterns, VF changes in concentric contraction were relatively easier to detect because stimuli were simply moved from the periphery to the center point. The examiner did not need to add any vectors and thus, there was less influence of examiner bias on the test results. In the case with a temporal residual island only, all the kinetic programs except Humphrey could detect the VF

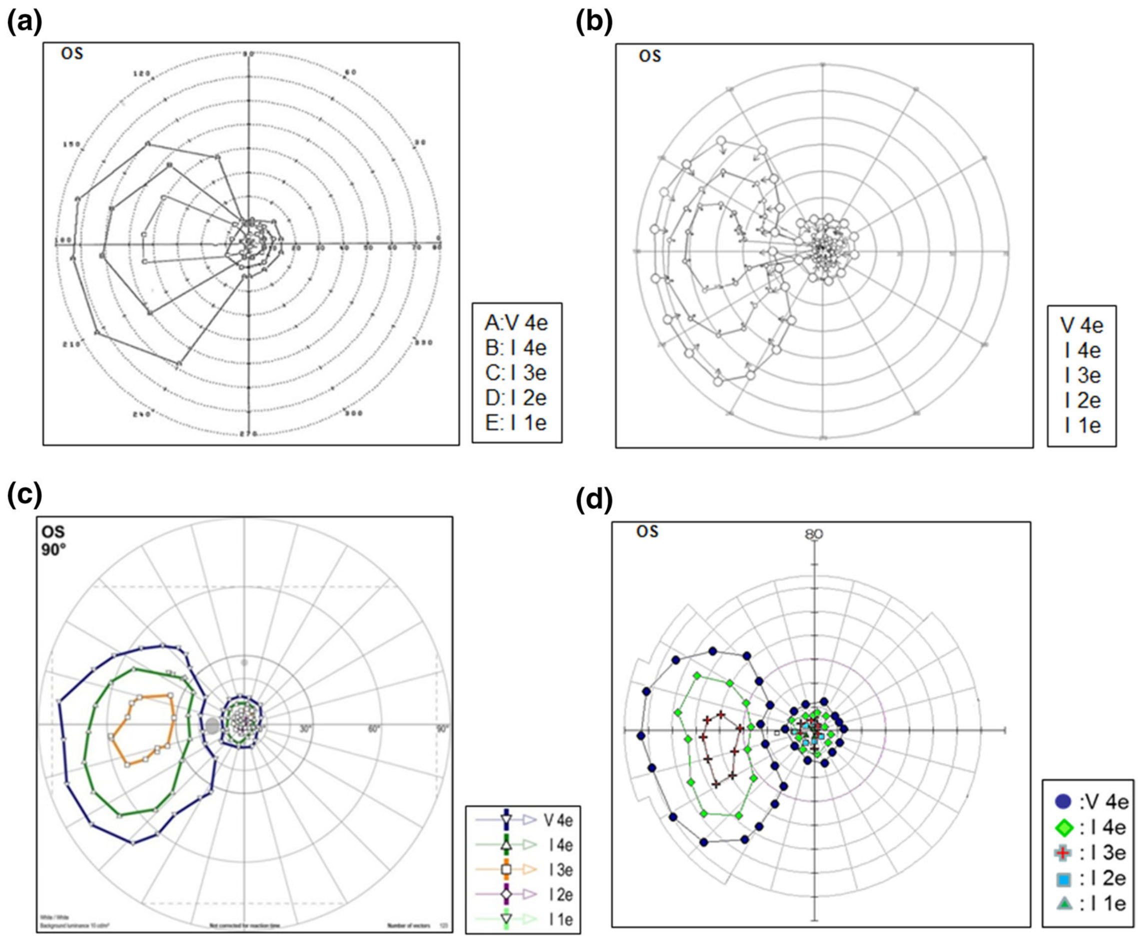


Fig. 5 Results for the pattern with a small central island with a temporal island. **a** Humphrey. **b** OCULUS. **c** OCTOPUS GKP. **d** Kowa. OCTOPUS GKP and Kowa correctly detected the VF pattern

changes (Fig. 4). The isopters depicted by Humphrey for the temporal residual island were connected to the central point and this had caused a restriction on stimulus presentation. The test target was moved from the periphery to the center point only along previously determined meridians and the examiner could not freely add vectors to any area in the VF. In the case of a small central island with a temporal island, only Kowa and OCTOPUS GKP detected the VF changes (Fig. 5). Humphrey could not evaluate the separated VF and depicted connected isopters for the separate islands. OCULUS could evaluate the separated VF, but its algorithm had difficulty drawing separate isopters for this VF pattern. Only OCTOPUS GKP could correctly detect and depict the VF changes in the ring scotoma. Humphrey could not detect the VF defect but OCULUS and Kowa could. However, OCULUS could not fill in the scotoma and Kowa completely filled in both the scotoma and the inner isopter. Neither OCULUS nor Kowa could depict the correct shape of the ring scotoma (Fig. 6). Of the four programs, OCTOPUS GKP was the only method that precisely detected and depicted all four VF patterns. OCTOPUS GKP did not have restrictions on the presentation of test targets. In addition, its algorithm had no difficulty in drawing isopters and was sufficient to fill in only the ring area. Only OCTOPUS GKP could correctly depict all four defect patterns probably because it was the only kinetic program complete with all these function.

OCTOPUS GKP also had relatively shorter test duration than the other three methods. We believe that the differences in test duration among these semi-automated programs were due to the different lengths of time required for manual operations such as vector selection and determining test conditions. More complicated or difficult operational tasks for the examiner would result in longer test duration. For instance, the test duration for Kowa to depict the ring scotoma pattern was almost twice as long as the duration for OCTOPUS GKP. OCTOPUS GKP was directly operated using an electronic pen and a touch screen. It had no restrictions on the presentation of test targets or problems in isopter drawing and filling in the scotoma. Previous studies also report on the easy-to-use system of OCTOPUS GKP [7, 9]. On the other hand, the operation of the Kowa program

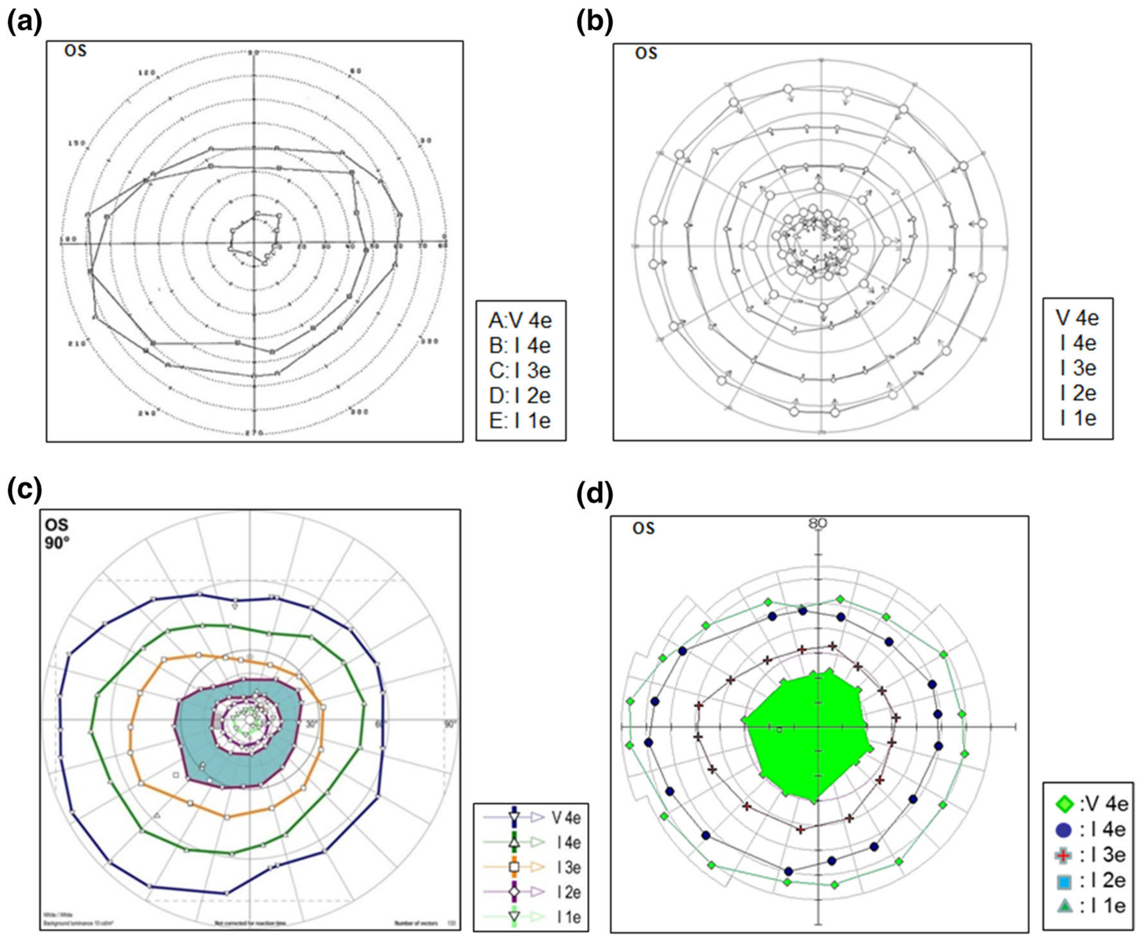


Fig. 6 Results for the pattern with a ring scotoma. **a** Humphrey. **b** OCULUS. **c** OCTOPUS GKP. **d** Kowa. Only OCTOPUS GKP correctly detected the VF pattern

was more time-consuming. Furthermore, its drawing software was not entirely capable of depicting the ring scotoma and hence the test duration was further extended. Humphrey, OCULUS, and OCTOPUS had almost the same test range for the peripheral VF as Goldmann MKP, while Kowa had a slightly narrower range due to the structure of its cupola.

This study had some limitations. We only simulated four defect patterns this time. In the future, more defect patterns with distinctive features could further differentiate various kinetic methods. In addition, in order not to extend the test duration, there was only one subject in the plastic eye cup trial with the four defect patterns and all the tests were performed by the same examiner to minimize bias. In future the number of subjects needs to be increased for better reproducibility as well as to test if there are any intra-individual differences in test duration or results. Although we could successfully monitor the subject's fixation in this study, other examiners might find it difficult to monitor the subject's fixation through a plastic eye cup with a defect pattern made of a light transmission filter. Careful fixation confirmation will be necessary.

We tested and compared the four methods with the same VF patterns in this study to evaluate the latest available automated kinetic methods. Automated kinetic perimetry has some common drawbacks such as examiner bias since additional meridians and the final isopter are determined and drawn by the examiner. Inevitably, the examiner's skill level and experience substantially affects the test precision. Such problems can only be solved by the establishment of a fully automated kinetic method, a system completely free from examiner's bias.

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Conflicts of interest All authors declare that they have no competing interest.

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