Photopic Negative Response of Focal Electoretinograms in Glaucomatous Eyes

Shigeki Machida, Yoshibaru Toba, Aki Obtaki, Yasutaka Gotoh, Muneyoshi Kaneko, and Daijiro Kurosaka

PURPOSE. To determine the clinical importance of the photopic negative response (PhNR) of the focal electoretinogram (fERG) for diagnosing glaucoma.

METHODS. Fifty-nine eyes of 38 patients with open-angle glaucoma (OAG), 12 glaucoma suspects, and 32 eyes of 32 normal controls were studied. The fERGs were elicited by a 15° stimulus spot on the macula region, the supero-temporal, and infero-temporal regions of the macula. The mean of the visual sensitivity was measured by standard automated perimetry (SAP). The optimal cutoff amplitudes of the focal PhNR and ratios of the focal PhNR/b-wave amplitudes that discriminated glaucomatous eyes from normal eyes were obtained from the receiver operating characteristic curves.

RESULTS. The amplitudes of the PhNR were significantly smaller in patients with OAG than in normal controls ($P < 0.00001$). A curvilinear relationship was found between the mean sensitivity (dB, on log scale) and the PhNR amplitude, and between the mean sensitivity and the PhNR/b-wave amplitude ratio. After converting the mean sensitivity from a logarithmic to a linear scale, the amplitude of the PhNR and PhNR/b-wave amplitude ratio were linearly correlated with the SAP-determined visual sensitivity in all retinal areas ($r = 0.428-0.544$, $P < 0.0001$). When the optimal cutoff values were used, the sensitivity and specificity of the PhNR/b-wave amplitude ratio were 98.3% and 90.1%, respectively.

CONCLUSIONS. The reduction of the focal PhNR amplitude was associated with a local decrease in the retinal sensitivity in OAG. The high sensitivity and specificity suggest that the focal PhNR can be used to detect functional loss in OAG. (Invest Ophthalmol Vis Sci. 2008;49:5636–5644) DOI:10.1167/iovs.08-1946

The photopic negative response (PhNR) is a negative wave that follows the photopic b-wave; it originates from the activity of retinal ganglion cells (RGCs) and their axons, which receive signals from cones. Evidence has been accumulating that the PhNR can be used to evaluate the functional condition of the neurons in the inner retina of patients with optic nerve diseases and inner retinal diseases.

Open-angle glaucoma (OAG) is a disease of the inner retina that affects the RGCs and their axons. Because the activity of RGCs contributes to the PhNR, it has been studied extensively in eyes with OAG. Viswanathan et al. demonstrated that the amplitude of the PhNR is significantly correlated with the visual sensitivity obtained by standard automated perimetry (SAP) and the cup/disc ratio determined by ophthalmoscopy.

Recent advances in imaging technology have allowed investigators to evaluate the structure of the optic nerve head and retinal nerve fiber layer thickness (RNFLT) quantitatively. Experiments conducted in our clinic have shown that the amplitude of the full-field PhNR was highly correlated with the RNFLT measured by optical coherence tomography (OCT) in patients with optic nerve atrophy induced by trauma, compression, and inflammation. Another of our studies, conducted on patients at different stages of glaucoma, showed that the PhNR amplitude was significantly correlated with the optic disc rim area, the cup/disc ratio area, and the RNFLT. The sensitivity and specificity of the PhNR amplitude of the full-field ERG to differentiate glaucomatous from normal eyes were 77% and 90%, respectively, when the optimal cutoff values were used.

However, the sensitivity decreased to 57% for patients with early-stage glaucomatous visual field defects, indicating that the PhNRs of the full-field ERGs are not suitable for identifying patients with early-stage glaucoma.

The full-field photopic ERGs are elicited by Ganzfeld stimuli, and they represent the sum of the activity of neurons across the entire retina. However, the initial glaucomatous changes begin in localized areas of the retina and optic nerve head, and these are manifested as localized visual field defects and enlargement of the optic disc. Therefore, it is not surprizing that the full-field ERGs are not altered in eyes at the early and even at the intermediate stage of glaucoma even if focal visual field defects are already present.

Miyake et al. developed an ERG stimulating and recording system that allowed them to record responses from focal retinal areas while viewing the location of small stimulus spots on the ocular fundus. We used a similar instrument to record focal responses from the paracentral regions of the retina, which are preferentially affected at the early stage of glaucoma. Preliminary data demonstrated that the responses elicited by this system were indeed focal, and the amplitudes of the PhNR of the full-field ERGs and the focal ERGs (fERGs) were attenuated in patients with optic nerve atrophy. This strongly suggests that the PhNRs of the fERGs, or focal PhNRs, represent the activity of RGCs in localized retinal areas. Relevant to the present study, Colotto et al. reported that the PhNRs of the fERGs were attenuated in patients with early glaucoma. However, they only recorded fERGs from the macular region of 11 patients with early OAG.

The aims of our study were twofold. The first was to determine whether a significant correlation existed between the focal PhNR and the visual sensitivity determined by SAP. The second was to determine whether it is possible to differentiate glaucomatous from normal eyes by the characteristics of the focal PhNRs.
**METHODS**

**Patients**

Seventy-one eyes of 38 patients with OAG were studied. The patients, whose ages ranged from 47 to 83 years with a mean ± SD of 68.9 ± 8.7 years, were being treated in the Glaucoma Unit of the Iwate Medical University Hospital. The diagnosis of OAG was based on the presence of a glaucomatous optic disc associated with visual field defects measured by SAP and an open angle confirmed by gonioscopy. The presence of glaucomatous optic disc was determined by the guideline of Japanese Society of Glaucoma developed in 2005 (http://www.glaucoma.or.jp/en/number/guideline/glaucoma2.jsp). According to the diagnostic criterion for minimal abnormality in the visual field,21 a visual field defect was determined to be glaucomatous when it met one of three criteria: (1) the pattern deviation plot showed a cluster of three or more non-edge points that had lower sensitivities than that in 5% of the normal population (P < 0.05) and one of the points had a sensitivity that was lower than 1% of the population (P < 0.01); (2) the value of the corrected pattern SD was lower than that of 5% of the normal visual field (P < 0.05); or (3) the Glaucoma Hemifield Test showed that the field was outside the normal limits. Of the 71 eyes, 12 did not meet these criteria and were designated as glaucoma suspects.

**Visual Field Analysis**

Static visual field analysis was performed (Humphrey Visual Field Analyzer, Model 750, Humphrey Instruments, San Leandro, CA). The SITA Standard strategy was applied to program 10-2 and 24-2, and the measurements of visual sensitivity were made after at least 5 minutes of adaptation to the background lights.

The mean of the visual sensitivity obtained by the 10-2 program was taken to be the visual sensitivity of the central retinal area. The averaged visual sensitivity of nine plots in the superior/nasal and inferior/nasal visual field of 24-2 program was assumed to represent the visual sensitivity in the inferior/temporal and superior/temporal retinal areas, respectively (Fig. 1C). The dB is 10 × log (1/Lambert). We converted all visual sensitivity of each measured point (dB, log unit) to 1/Lambert (linear unit) which was averaged for each retinal area. These averaged values were designated the mean linear sensitivity. The mean linear sensitivity was then converted to log units to obtain the mean sensitivity in dB units.

The fERGs were recorded from these retinal areas, and we calculated whether a significant correlation existed between the mean of visual sensitivity of each retinal area with the amplitudes of the focal PhNRs elicited from the corresponding retinal area.

**Quantitative Assessments of Optic Nerve Head and Retinal Nerve Fiber Layer**

The morphology of the optic nerve head was determined with the use of confocal scanning diode technology (HRTII; Heidelberg Retina Tomograph II; Heidelberg Engineering GmbH, Heidelberg, Germany). Three 15° field-of-view scans, centered on the optic nerve head, were obtained and automatically averaged by the program of the instrument (IR1-V1.7.2/4622). Experienced operators evaluated the quality of the images and outlined the disc margin while viewing the photograph of the optic nerve head.

The retinal nerve fiber layer (RNFL) birefringence around the optic nerve head was measured by scanning laser polarimetry with a conversion to variable corneal compensation (GDx-VCC; Carl Zeiss Meditec, Inc., Dublin, CA).

**Statistical Analyses**

The significance of the differences was determined by the two-tailed Student’s t-test for paired data. Pearson’s coefficient of correlation was used to determine the degree of correlation between ERG parameters and SAP-determined sensitivity. Statistical significance was set at P < 0.05.

The sensitivity of the focal PhNR indicates how well the focal PhNR can separate glaucomatous from normal eyes, and the specificity shows how well the focal PhNR can differentiate normal from glaucomatous eyes. The sensitivity and specificity were calculated with standard formulas for the focal PhNR amplitude and the focal PhNR/b-wave amplitude ratio. We used receiver operating characteristic (ROC) curves to determine the cutoff values that yielded the highest likelihood ratio. The area under the curve (AUC) was obtained to compare the ROC curves. These analyses were performed using commercial

NEUROPACK, MEB 9102; Nihonkoden, Tokyo, Japan). Three to five hundred responses were averaged at a stimulation rate of 5 Hz.
RESULTS

Representative Cases

Representative fERGs recorded from the center, superior/temporal, and inferior/temporal areas are shown in Figure 1D. Although the waveforms of the fERGs recorded from the three different retinal areas did not change substantially, the b-wave amplitude of normal controls was significantly larger in the center than in the superior/temporal (center), the supero-temporal (superior/temporal), and the infero-temporal (inferior/temporal) regions of the macula. The shape of the focal PhNRs differed from those of the full-field photopic ERGs by the absence of a prominent i-wave that is seen after the b-wave.22

The structural and functional results of a 59-year-old man with OAG whose visual field defect was located in the inferior visual field (superior retinal area) are shown in Figure 2A. In
The average a-wave amplitude of the focal ERGs was slightly but significantly smaller in glaucomatous eyes than in the normal eyes in all retinal areas ($P < 0.05$). This is consistent with the previous results in which the photopic ERG a-wave was attenuated in eyes with ischemic optic neuropathy and with OAG.5,7,9 On the other hand, the amplitudes of the b-wave and $\Sigma$OPs of the fERGs of glaucomatous eyes were not significantly different from that of normal eyes.

In contrast, the amplitude of the focal PhNR and the focal PhNR/b-wave amplitude ratio were significantly smaller in glaucomatous eyes than in normal or glaucoma suspect eyes ($P < 0.0001$). Even in the glaucoma suspect eyes, these two ERG parameters were significantly smaller than in normal controls in all retinal areas tested ($P < 0.05$).

**Correlation between Focal PhNRs and Visual Sensitivity Determined by SAP**

The amplitudes of the focal PhNR and the focal PhNR/b-wave ratio are plotted against the mean of the visual sensitivity measured for the central, superior/temporal, and inferior/temporal retinal areas in Figures 4A to 4C, respectively. There were curvilinear relationships between the visual sensitivity on log scale (dB) and the focal PhNR amplitude or focal PhNR/b-wave amplitude ratio in all retinal areas. The curves in Figure 4 were fit to the equation based on the Hood50,51 model: $R = A \times 10^{S+5} - 30 + B$, where $R$ is the focal PhNR amplitude or the focal PhNR/b-wave amplitude ratio, $A$ is the focal PhNR amplitude or the focal PhNR/b-wave amplitude ratio of normal RGCs, $S$ is mean of visual sensitivity determined by SAP, and $B$ is the basal level of the focal PhNR amplitude or the focal PhNR/b-wave amplitude ratio when a patient has lost sensitivity to light.

The visual sensitivity is converted from a log (dB) to a linear scale in Figure 5A to 5C. The amplitude of the focal PhNR and the focal PhNR/b-wave ratio were linearly and significantly correlated with the visual sensitivity on linear scale in all retinal areas ($P < 0.0001$). The 95% confidence intervals (95% CI) for the coefficient of correlations and slopes are shown in Table 1.

**Sensitivity and Specificity of Focal PhNR Amplitude and Focal PhNR/b-wave Amplitude Ratio**

The cutoff values were varied in decrements of 0.1 $\mu$V for the focal PhNR amplitude and 0.01 for the focal PhNR/b-wave amplitude ratio for the pooled data from glaucomatous and normal eyes. The sensitivity and specificity were obtained for each cutoff value and plotted to determine ROC curves (Fig. 6). The ROC curves of the focal PhNR amplitudes (Fig. 6A) and focal PhNR/b-wave amplitude ratios (Fig. 6B) are plotted for the central, superior/temporal, and inferior/temporal retinal areas. The AUC were larger for the focal PhNR/b-wave amplitude ratio than for the focal PhNR amplitude (Table 2). The sensitivity and specificity were obtained by employing optimal cutoff values giving the maximal likelihood ratio (Table 2). The optimal cutoff values for the focal PhNR amplitude were 0.75, 0.65, and 0.75 $\mu$V for the central, superior/temporal, and inferior/temporal retinal areas, respectively. The values for the focal PhNR/b-wave amplitude ratio were 0.225, 0.225, and 0.325 for the corresponding retinal areas.

If eyes were classified as being glaucomatous when their focal PhNR amplitudes or focal PhNR/b-wave amplitude ratio were less than the cutoff values in either retinal areas (combined criterion in Table 2), the sensitivity increased to 94.9 (95% CI: 85.9–98.9) and 98.3% (90.9 to 100) for the focal PhNR amplitude and the focal PhNR/b-wave amplitude ratio, respectively (Table 2). The specificity obtained by the combined criteria was 84.4 (95% CI: 67.2 to 94.7) and 90.1% (75.8 to 96.8) for the focal PhNR amplitude and the focal PhNR/b-wave amplitude ratio, respectively.
Intersession Reproducibility

The CVs for the focal b-wave amplitude in normal controls were 7.14 ± 5.98% for the central, 14.30 ± 7.28% for the superior/temporal, and 9.03 ± 7.53% for the inferior/temporal retinal areas. The corresponding values for the focal PhNR amplitude were 15.90 ± 10.83% for the central, 14.20 ± 7.28% for the superior/temporal, and 9.21 ± 4.96% for the inferior/temporal retinal areas. Although the CV for the focal PhNR amplitude was significantly larger than the focal b-wave in the central retinal areas (P < 0.05), the differences were not significant in the other retinal areas. The CVs of the focal PhNR in the superior and inferior/temporal retinal areas were comparable to those of the full-field PhNR.

DISCUSSION

The ability to record fERGs has enabled investigators to evaluate the properties of the retina in localized retinal areas. The functional properties of the outer and middle retinal layers have been investigated in various retinal and choroidal diseases. However, only a single study has been conducted to assess the inner retinal function using the focal PhNR. Colotto et al. were the first to report that the focal PhNRs were reduced in patients with OAG. They recorded the fERGs from only the macular region of 11 eyes of 11 patients with early OAG. In the present study of 59 eyes of 38 patients, we recorded the fERG from the macular region as well as the supero-temporal and infero-temporal retinal areas, where RGCs are preferentially affected by glaucoma. We found a significant correlation between the amplitude of the focal PhNR and local retinal sensitivity. In addition, we demonstrated that the focal PhNR can be used to discriminate glaucomatous eyes from normal eyes. Thus, our results appear to be the most comprehensive demonstration on the effect of OAG on the properties of the focal PhNRs.

Correlation between Focal PhNRs and Visual Sensitivity of Local Retinal Areas

Colotto et al. demonstrated that the focal PhNR recorded from the macular region was linearly correlated with mean deviation of SAP. We examined a larger number of subjects, and found a different relationship from their results. The focal PhNR amplitude and focal PhNR/b-wave amplitude ratio were associated.

FIGURE 4. Relationships between means of the visual sensitivity (dB) and the focal PhNR amplitude or the focal PhNR/b-wave amplitude ratio obtained from the central (A), superior/temporal (B), and inferior/temporal (C) retinal areas.

A

B

C

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with the visual sensitivity (dB, on the log scale) in a curvilinear fashion. Earlier, we found that the relationship between the mean deviation of SAP and the full-field PhNR could be best fit by a log-linear relationship. A similar relationship has also been found between the pattern ERG amplitude and visual field sensitivity. The curvilinear relationship between the focal PhNR and visual sensitivity (dB) indicates that a large reduction in the focal PhNR amplitude was associated with only a small reduction of SAP-determined visual sensitivity on the log scale (dB) at the early stage of glaucoma. In addition, at the advanced stage of glaucoma there would be a small reduction of the focal PhNR amplitude corresponding with a large reduction of SAP.

TABLE 1. Correlation between Visual Sensitivity and PhNR

<table>
<thead>
<tr>
<th>Region</th>
<th>R</th>
<th>Slope</th>
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</thead>
<tbody>
<tr>
<td>PhNR amplitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center</td>
<td>0.428 (0.256–0.574)</td>
<td>0.000300 (0.000175–0.000426)</td>
</tr>
<tr>
<td>Superior/temporal</td>
<td>0.529 (0.374–0.655)</td>
<td>0.000406 (0.000253–0.000559)</td>
</tr>
<tr>
<td>Inferior/temporal</td>
<td>0.451 (0.285–0.595)</td>
<td>0.000550 (0.000330–0.000771)</td>
</tr>
<tr>
<td>PhNR/b-wave amplitude ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center</td>
<td>0.529 (0.374–0.655)</td>
<td>0.000103 (0.0000706–0.000136)</td>
</tr>
<tr>
<td>Superior/temporal</td>
<td>0.544 (0.392–0.667)</td>
<td>0.000156 (0.000107–0.000205)</td>
</tr>
<tr>
<td>Inferior/temporal</td>
<td>0.539 (0.385–0.663)</td>
<td>0.000196 (0.000134–0.000258)</td>
</tr>
</tbody>
</table>

Values in parentheses indicate 95% confidence intervals. PhNR, photopic negative response; R, correlation coefficients.
decrease of visual sensitivity on the log scale. Taken together, the focal PhNR should be suitable for detecting early glaucomatous changes in localized areas of the retina, but is not suitable for following patients with advanced glaucoma.

When the visual sensitivity is converted from a log scale to a linear scale and replotted against the focal PhNR amplitude or the focal PhNR/b-wave amplitude ratio, we found linear correlations between these ERG parameters and the visual sensitivity in all retinal areas. A similar finding has been reported in relationship between the pattern ERG amplitude and the visual sensitivity (dB) on the linear scale.41 These observations indicate that the curvilinear relationship between visual sensitivity and inner retinal responses can be partially explained by the fact that the visual sensitivity is recorded in logarithmic units (dB) by SAP.

FERGs and i-Wave

The i-wave is a positive-going wave that follows the b-wave and is superimposed on the full-field PhNR. It is very prominent in the photopic full-field ERGs.5,22 Therefore, some attempts have been made to reduce the amplitude of the i-wave, such as use of a red stimulus on a blue background or long duration stimuli.2,4,6,9,42

The results of this study showed that the i-wave of the focal ERGs was much smaller than that of the full-field ERG. The i-wave is produced by an interaction of the ON- and OFF-responses,22 and Kondo et al.43,44 demonstrated that the OFF/ON-response ratio (d-wave/b-wave amplitude ratio) of the multifocal ERGs increased with increasing retinal eccentricity. This indicated that the OFF response contributes less to the amplitude of the i-wave in the macular area. This can explain our findings that the i-wave of the fERG is smaller in the macular and peri-macular areas. However in glaucomatous eyes, the i-wave appeared after the b-wave even in the fERG because of a decrease in the counteracting focal PhNR, making it difficult to determine the trough of the focal PhNR. Therefore, we measured the focal PhNR amplitude at a fixed time point.

Sensitivity and Specificity of fERGs

In a previous study, we showed that the sensitivity and specificity of the full-field PhNR recorded from glaucomatous and normal eyes using red stimuli on a blue background were 77% and 90%, respectively.9 The sensitivity and specificity of the focal PhNR recorded from each retinal area were comparable to those obtained for the full-field PhNR.

Our results with the focal PhNR demonstrated that a combination of the data obtained from the three retinal areas improved the sensitivity to detect glaucoma to 94.9% and 98.3% for the focal PhNR amplitude and focal PhNR/b-wave amplitude ratio, respectively. It is possible that the patients could have been classified glaucomatous based on a SAP visual field defect that was not present in the retinal area from which the focal PhNR was measured. Although in such cases the sensitivity of the focal PhNR will be low, the sensitivity values will improve when the combined criteria are used. Based on these results, we recommend that fERGs should be recorded from the macula and the peri-macular regions and be used to increase the ability to detect functional changes in glaucomatous eyes. However, the combined criteria reduced specificity to 84.4% and 90.1% for the focal PhNR amplitude and focal PhNR/b-wave amplitude ratio, respectively. It should be noted that the incidence of false positive will be increased when the combined criteria are used.

Table 2. Ability of Discriminating Glaucoma by the Focal ERG

<table>
<thead>
<tr>
<th>Region</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhNR amplitude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center</td>
<td>76.3 (63.4–86.4)</td>
<td>93.8 (79.2–99.2)</td>
<td>0.93 (0.87–0.98)</td>
</tr>
<tr>
<td>Superior/temporal</td>
<td>73.2 (59.7–84.2)</td>
<td>96.7 (82.8–99.9)</td>
<td>0.89 (0.82–0.96)</td>
</tr>
<tr>
<td>Inferior/temporal</td>
<td>77.2 (64.2–87.3)</td>
<td>93.3 (77.9–99.2)</td>
<td>0.94 (0.90–0.98)</td>
</tr>
<tr>
<td>Combined criteria</td>
<td>94.9 (85.9–98.9)</td>
<td>84.4 (67.2–94.7)</td>
<td>NA</td>
</tr>
<tr>
<td>PhNR/b-wave amplitude ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center</td>
<td>74.6 (61.6–85.0)</td>
<td>96.9 (83.8–99.9)</td>
<td>0.94 (0.89–0.99)</td>
</tr>
<tr>
<td>Superior/temporal</td>
<td>69.7 (55.9–81.2)</td>
<td>96.7 (82.8–99.9)</td>
<td>0.90 (0.83–0.96)</td>
</tr>
<tr>
<td>Inferior/temporal</td>
<td>91.2 (80.7–97.1)</td>
<td>96.7 (82.8–99.9)</td>
<td>0.96 (0.91–1.00)</td>
</tr>
<tr>
<td>Combined criteria</td>
<td>98.3 (90.9–100)</td>
<td>90.1 (75.8–96.8)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Values in parentheses indicate 95% confidence intervals. PhNR, photopic negative response; AUC, area under the curve; NA, not available.
Contribution of RGCs in Shaping a-Wave of fERG

Interestingly, the a-wave amplitude was slightly but significantly attenuated in glaucomatous eyes in the present study. Rangaswamy et al. demonstrated that the a-wave amplitude of the full-field cone ERG was reduced in patients with optic neuropathy induced by ischemia, which is consistent with our result regarding the a-wave. These results suggest that responses originating from the RGCs partially shapes the a-wave of the fERGs. However, the a-wave amplitude cannot be used to discriminate glaucomatous eyes from normal eyes because most of the a-wave amplitudes of glaucomatous eyes overlapped with the normal values.

Advantage of fERGs over Pattern ERGs

Pattern ERGs also originate from the activity of RGCs, and are another retinal response that has been used to detect functional abnormalities in glaucoma. Earlier studies have demonstrated a significant correlation between the pattern ERG amplitude and visual field defect or structure of the RNFL and optic disc. In addition, the pattern ERG can detect functional loss earlier than SAP. The fERGs appear to be better than the pattern ERG in the following ways. First, the retinal area to be tested can be selected while viewing the ocular fundus. The stimulus area is smaller in the fERG even using a 15° spot than in the pattern ERG, which then allows a better resolution of the functional analysis. Second, it is not necessary to correct the refractive errors for the fERG. And third, we can record the a- and b-waves and OPs simultaneously in the fERG, which enables us to concomitantly analyze the function of the outer and middle retinal layers.

However, in contrast to the pattern ERG, the fERG possesses an essential problem in which scattered light from the stimulated area evokes retinal responses, the stray light effect. In previous studies, Miyake et al. developed stimulus conditions using background light that minimized the stray light effect. We adjusted stimulus conditions to produce fERG waveforms with similar amplitude to those that Miyake et al. have reported. Therefore, it is assumed that we reduced the contribution from the stray light to a minimum.

Limitations of the Present Study

One of the limitations of this study was that we included both eyes of most of the patients with glaucoma in data analyses. We did this because there were differences in the visual field defects in the two eyes. However, this inclusion may reduce the variability among the eyes by eliminating the effect of individual variations.

Because the focal PhNR is a slow wave, Colotto et al. adjusted the low cut filter to 0.3 Hz, which theoretically recorded the entire focal PhNR. However, lowering the low cut filter produces slow drifts in the baselines, which can affect the shape of the focal PhNR in the clinical recordings. Therefore, we decided to set the low cut filter at 5 Hz and kept in mind that this setting could modify and reduce the focal PhNR amplitude. The CVs of the focal PhNR amplitude were comparable to those of the focal b-wave except for the central retina, indicating the focal PhNR is unlikely affected by the baseline drifts in our recording condition. Future studies are needed to determine the proper ranges of low cut filters for recording the focal PhNR in the clinical practice.

Conclusions

The decrease in visual sensitivity in glaucomatous eyes was correlated with a reduction of the focal PhNRs. The curvilinear relationship between the visual sensitivity (dB) on log scale and the focal PhNR amplitudes indicates a large reduction of the focal PhNR amplitude with small change in the SAP-determined sensitivity in the early stage of glaucoma. After converting the visual sensitivity from the log to linear units, the focal PhNR amplitudes were linearly correlated with visual sensitivity on linear scale. The high sensitivity and specificity suggest that the focal ERG PhNR can be used as a functional measure to detect functional loss in glaucomatous eyes.

Acknowledgments

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References


