The Reliability of a Video-Enhanced Hirschberg Test Under Clinical Conditions

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Purpose. To examine the reliability and usefulness of a video-based Hirschberg test under clinical conditions.

Methods. The authors estimated ocular deviation in 87 patients with strabismus through automated analysis of corneal reflex displacement using a video refractor. The reproducibility of measurement, the comparison with the prism and alternate cover test (PACT), and the distribution of the Hirschberg ratio were investigated.

Results. The 95% limits of agreement of the video-based Hirschberg test evaluated by repeated measurements were ±0.18 mm (equivalent to ±2.2° or ±3.8 prism diopters [PD] of calculated strabismic deviation) for the horizontal deviation and ±0.28 mm (equivalent to ±3.4° or ±5.9 PD) for the vertical deviation. The 95% limits of agreement between the Hirschberg measures and the PACT were within ±7.8° or ±13.7 PD. The average (± SD) Hirschberg ratio was 12.3 ± 1.2°/mm or 21.8 ± 2.1 PD/mm.

Conclusions. The video-enhanced Hirschberg measurement shows good reproducibility and ease of application, even in the testing of infants. In quantitative analysis, however, systematic measurement error resulting from intersubject variance of the Hirschberg ratio should be taken into consideration.

The Hirschberg test consists of the estimation of the strabismic angle based on the decentration of the corneal light reflex produced by a small point source of light, the first Purkinje image. This simple test is used frequently when inadequate cooperation or reduced vision precludes the use of other methods. 

To obtain the strabismic angle (in degrees or prism diopters [PD]), the observer multiplies the estimated decentration (in millimeters) of the corneal reflex by some suitable conversion factor termed the Hirschberg ratio. Recent investigations have indicated that this ratio is 12°/mm or 21 PD/mm. Accordingly, the displacement of the corneal reflex per degree is too small to determine precisely with naked eye observation. Putnam also noted that the precision in assessment of the corneal reflex position was greater than 0.5 to 1 mm. As a consequence, the Hirschberg test generally has been acknowledged to provide only a gross approximation of the strabismic deviation and not to be suitable for quantitative purpose.

In some types of strabismus, early surgical alignment of the eyes within the first or second year of life is thought to be prerequisite for normal development of binocular visual function. Therefore, an easy to apply but more reliable technique, on the basis of which surgical dosage can be decided, is now required.

Recently, the strategy of finding the corneal reflex position on photographic or videographic images of the eyes was proposed. In experimental studies, the precision of these methods was found to be within a few degrees, and they are thus notably more precise than the traditional Hirschberg test. For application in clinical examination, we were particularly interested in the development of the Hirschberg test through video image processing because it provides immediate results.

Some geometric analyses have suggested that there is variation among subjects for the Hirschberg
TABLE 1. Diagnoses of Patients Using a Video-Enhanced Hirschberg Test

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermittent exotropia</td>
<td>32 (36.8)</td>
</tr>
<tr>
<td>Microtropia</td>
<td>13 (14.9)</td>
</tr>
<tr>
<td>Infantile esotropia</td>
<td>10 (11.5)</td>
</tr>
<tr>
<td>Acquired esotropia</td>
<td>8 (9.2)</td>
</tr>
<tr>
<td>Consecutive esotropia</td>
<td>7 (8.0)</td>
</tr>
<tr>
<td>Accommodative esotropia</td>
<td>7 (8.0)</td>
</tr>
<tr>
<td>Abducens nerve palsy</td>
<td>3 (3.4)</td>
</tr>
<tr>
<td>Divergent palsy</td>
<td>2 (2.3)</td>
</tr>
<tr>
<td>Duane's syndrome</td>
<td>2 (2.3)</td>
</tr>
<tr>
<td>Overaction of inferior oblique muscles</td>
<td>2 (2.3)</td>
</tr>
<tr>
<td>Consecutive esotropia</td>
<td>1 (1.1)</td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
</tr>
</tbody>
</table>

diopter because it depends on the two biometric parameters of the corneal curvature and anterior chamber depth. Because the intersubject variance of the Hirschberg ratio can be a source of systematic measurement error, we cannot overlook this problem to take full advantage of the precision provided by the above-mentioned image analysis.

In the current study, we carried out the video-based Hirschberg test under clinical conditions using a commercially available video refractor. We then verified the reliability of this test by assessing the reproducibility of the measurement, the degree of agreement between this test and the prism and alternate cover test (PACT), and the distribution of the Hirschberg ratio.

METHODS

Subjects

Our subjects consisted of 87 patients with strabismus (Table 1; mean age, 17.5 years; standard deviation, 22.9 years; median age, 17 years; age range, 4 months to 75 years) recruited randomly at the Strabismus Clinic at Okayama University. We excluded patients with very large deviations (>45 PD) from this study because we sometimes did not obtain any result for them with the video-based Hirschberg test. The range of horizontal deviation (as measured by the PACT or the Krimsky test) was 4 to 45 PD of exotropia and 4 to 40 PD of esotropia. Vertical ocular misalignment was also found in some patients; however, we could not identify the range because some patients had vertical deviation that could not be measured satisfactorily by any technique. The anisocycloplegic refraction, which was measured by using the video refractor described below, ranged from −4.25 to +3.50 diopters spherical equivalents. No patient was cognitively or developmentally disabled. Informed consent was provided by either the patient or the patient’s legal guardian after an explanation of the study purpose and procedures. This research followed the tenets of the Declaration of Helsinki.

Test Apparatus

For acquisition and processing of the video image, a video refractor PR1000 (Topcon, Tokyo, Japan) was used. Originally, it was designed for refractive screening of infants, and it has the capacity to measure the refractive error of both eyes simultaneously at a distance of 120 cm. We thus could apply this apparatus directly to Hirschberg measurement without modification.

A CCD video camera and a coaxial infrared light-emitting diode (wavelength, 800 μm) with which the PR1000 is equipped were used to take the subject’s face image. Its optics show a narrow depth of focus (approximately ±1 cm) and, therefore, testing distance was assured. A scale reference was not necessary. Because this apparatus was placed on an altazimuth mount that could be slid back and forth, the examiner could quickly adjust its alignment and focus. The acquisition time per frame was 0.033 seconds, and four successive frames were acquired on the frame grabbing hardware within 0.15 seconds for a single determination. A 166 × 300 pixel image of each eye was then extracted from the video signal and processed. The pixel resolution of the image was 7.7 pixels/mm horizontally and 9.1 pixels/mm vertically. The coordinates of the pupillary center were determined by computing the geometric centroid of a binary image of the pupil. The coordinates of the corneal light reflex were determined by computing a centroid from the gray scale image of the eye. The distance between these two centroids, which was calculated from four successive frames on average, was displayed in units of 0.1 mm in both the horizontal and vertical directions (Fig. 1). The calculation time was approximately 8 seconds.

Test Procedure

The subject either stood or sat 120 cm away from the PR1000. To estimate the strabismic deviation in the primary position, we used the fixation target of the PR1000 (a flashing red light-emitting diode with a small cross as an accommodative stimulus). The distance between this built-in target and the subject’s eye was 140 cm. While the subject was gazing at this target, the decentration of the corneal light reflex relative to the pupil center was measured twice by the PR1000, with an interval of at least 10 minutes. The strabismic deviation was obtained based on the corneal reflex asymmetry by subtracting the decentration of the right...
FIGURE 1. A video image of the bright pupils and the corneal reflections acquired by a video refractor. The lowest line shows the decentration of the corneal light reflex. On the left, L0.2 I0.2 indicates that the pupil for the subject’s right eye is located 0.2 mm lateral and 0.2 mm inferior to the corneal reflex. Similarly, M0.5 I0.2, on the right, indicates that the pupil for the left eye is located 0.5 mm medial and 0.2 mm inferior to the corneal reflex.

corneal reflex from the left. Testing was binocular in all instances. Spectacle correction was not worn because both reflections from the lens surface and distortion through the lens can interfere with this measurement. We did not use any instrument to fix the subject’s head. Parents held their infants’ heads to face straight ahead. We sometimes used sound, a synchronized repeated bleep, to attract the subject’s attention.

After the Hirschberg measurement, we performed the PACT using the same fixation target. Briefly, the cover was placed alternately over each eye, while the eye movement of redress was compensated for by using prisms. In 58 patients who participated in this procedure, the agreement between the video-based Hirschberg test and the PACT value was examined.

The Hirschberg ratio was assessed in 72 patients who allowed monocular occlusion with an eye patch. A horizontal tangent scale was placed at a distance of 110 cm from the subject, concentric with and perpendicular to the optical axis of the PR1000 (Fig. 2). Thirty small fixation targets, 15 on either side, were aligned horizontally on the scale at regular 5-cm intervals. Preliminarily, we verified the linearity of the displacement (mm) of the corneal light reflex relative to eye rotation (degrees) in three selected subjects who had neither refractive error nor fixation abnormality. Although the subject looked at each fixation target in turn, the horizontal location of the corneal light reflex was stored by the PR1000. To investigate the frequency distribution of the Hirschberg ratio, we selected two fixation targets placed at 55 cm on either side of the center. The width between the two targets, which was verified with a laser beam pointer mounted on a rotational positioning device, was equivalent to 51.63° visual angle from the subject’s eye position. We used this value as the common denominator of the Hirschberg ratio. While the subject was changing fixation between these two targets monocularly, the displacement of the corneal light reflex was measured by the PR1000. We used this value as the numerator of the individually estimated Hirschberg ratio.

Statistical Analysis

The obtained data were examined according to Bland and Altman’s method to determine the reproducibility of the video-based Hirschberg test. We took repeated measurements on a series of the patients and then calculated, for each subject, the numeric difference between the values obtained on two different occasions. These data were plotted on a difference versus mean plot (we do not know the absolute value, and the mean of the two measurements is the best estimate we have). The bias between the first and second measurement was assessed statistically as the mean of the differences compared to zero (paired t-test). The test–retest reproducibility was evaluated by determining the interval within which 95% of these differences lie, which was constructed as the mean of the differences ± 1.96 × SD of the differences. For determination of the magnitude of the difference between the video-based Hirschberg test and the PACT, the degree of measurement agreement was examined in the same way.

FIGURE 2. The setup (top) for the assessment of the Hirschberg ratio.
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Mean of two horizontal measurements (mm)

Mean of two vertical measurements (mm)

FIGURE 3. A difference versus mean plot for repeated measures of the video-based Hirschberg test for the horizontal (A) and the vertical (B) measurement. The horizontal line indicates the mean difference between the results, and the shaded area indicates the 95% limits of agreement (= mean difference ± 1.96 × SD of the differences). Negative values indicate exotropic deviations, and positive values represent esotropic deviations. The 95% limits of agreement were ±0.18 mm for the horizontal deviation and ±0.28 mm for the vertical deviation.

RESULTS

We succeeded in measuring the strabismic deviation in all 87 subjects with the video-based Hirschberg test, although the measurements were incomplete in six subjects (7%). The values obtained on two different occasions were highly correlated for both the horizontal measurement ($r = 0.997$) and the vertical measurement ($r = 0.936$). Figure 3A shows difference versus mean plots for the horizontal measurement. No relationship was observed between the difference and the mean, and the difference was $0.00 \pm 0.09$ mm (mean ± SD). The 95% limits of agreement for the reproducibility of horizontal measurement thus were ±0.18 mm. The difference versus mean plots for the vertical measurement are shown in Figure 3B. Again, no relation was observed between the difference and the mean, and the difference was $0.00 \pm 0.14$ mm (mean ± SD). The 95% limits of agreement for the reproducibility of vertical measurement were ±0.28 mm, and they were wider than those for the reproducibility of horizontal value ($P < 0.001$, F-test for homogeneity of variance). The difference between the two measurements according to age is shown in Figure 4.

FIGURE 4. The differences between two measures obtained on different occasions were plotted as a function of the patient’s age (in logarithmic scale). There is no significant relationship to age for horizontal measurement (A), although outlying values were sometimes found in patients younger than 2 years of age for vertical measurement (B).
The subject's age did not influence the reproducibility, at least for horizontal measurement.

A conventional plot and a difference versus mean plot comparing horizontal measurements obtained by the two different techniques of the video-based Hirschberg test and the PACT are presented in Figure 5. The values obtained by the two measurement methods were highly correlated ($r = 0.956$), and the difference was $0.78^\circ \pm 3.58^\circ$ (mean ± SD). The mean difference compared to zero (i.e., the bias) was not significant. The 95% limits of agreement between the two measuring methods were ±7.8°, or ±13.7 PD. In these plots, we found that the data points for five subjects were located far away from the others (outliers): Three of the subjects had intermittent exotropia, and two had accommodative esotropia.

A linear relationship between horizontal eye rotation and displacement of the corneal light reflex up to ±30° (±58 PD) was established in all three subjects. The correlation coefficient was high ($r = 0.998$ to 0.999). The slope of the regression lines ranged from 0.073 to 0.077 mm/degree, and the root mean square residual ranged from 0.046 to 0.073 mm. The displacement of the corneal light reflex during alternate gazing at the ±55 cm lateral targets was 3.67 ± 0.35 mm (mean ± SD).

As shown in Figure 6, the Hirschberg ratio was distributed normally (Gaussian). The mean (± SD) Hirschberg ratio was $12.3^\circ \pm 1.2^\circ$/mm, or $21.8 \pm 2.1$ PD/ram ($n = 143$). The maximum value was $15.6^\circ$/mm, and the minimum was $9.9^\circ$/mm.

**DISCUSSION**

The video-based Hirschberg measurement offers definite advantages in testing infants and young children who are unable to cooperate. First, the video image required for the measurement is captured in only 0.033 seconds and measures the horizontal and vertical ocular deviation simultaneously. Accordingly, to complete this test, it is necessary to get the subject's attention for only a brief moment. Next, this system evaluates the relative distance between the corneal light reflex and the pupillary center. Because this distance is little influenced by the subject's head movement as long as the gaze is not altered,$^{17}$ rigid head fixation of the subject with a chin rest or a head band is not necessary. These features are thought to contribute to the high success rate of this measurement. Next, it is not guaranteed that the subject will look at the desired target, although proper fixation is crucial in any method of quantifying the strabismic deviation. As Barry and colleagues$^{15}$ mentioned, the fixation can be checked only by repeated measurements and by verifying the consistency of the results. The video-based Hirschberg test provides immediate results and can be repeated. This allows us to confirm the fixation quality when proper fixation is doubtful. Finally, assessment of deviations at distance fixation is a disadvantage of the conventional Hirschberg test and of the Krimsky test as well.$^{1,5,12}$ For example, intermittent
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The mean (±SD) ratio is 12.3° ± 1.2°/mm, demonstrating a large intersubject variation in the Hirschberg ratio.

Exotropia is likely to be overlooked with the Hirschberg test because the ocular misalignment is easily compensated for by the motor fusion at near fixation. In the video-based Hirschberg measurement, 27 of the 32 patients (84%) with intermittent exotropia were determined to have significant ocular deviation. This result suggests that the 27 patients were exotropic under this testing condition. This fairly good success rate in the detection of intermittent exotropia probably resulted from the long testing distance, which was provided by the remote optical system of the PR1000.

We found that the results obtained with the video-based Hirschberg test were highly reproducible. The 95% limits of agreement were ±0.18 mm for the horizontal measurement and ±0.28 mm for the vertical measurement. These values correspond to ±2.2° (±3.8 PD) and ±3.4° (±5.9 PD), respectively, when converted to eye rotation with the average Hirschberg ratio we found in this study. Any manifest strabismus or time-series fluctuation of a strabismic deviation that is larger than these threshold values can be detected in principle; we could identify 7 of the 13 patients (54%) with microtropia with the video-based Hirschberg test alone.

The resolution of the CCD image sensor is generally poor compared with that of the photographic film. However, the coordinates of the corneal light reflex and the pupil can be determined with subpixel resolution by mathematical computation of the center of gravity (i.e., centroid) of their images. Moreover, the retroilluminated pupil, which was produced by arranging optically coincident lighting and collection apertures, was well defined regardless of the iris color. We think that the centroid coordinates of the pupil are a more reliable standard than the scleral–corneal limbus, which was often used in the photographic method but which is actually an indistinct boundary. Nevertheless, the measurement range with this technique is at present limited. When the eye is rotated over 25° or 45 PD, the intensity of the retroillumination of the entrance pupil is gradually decreased, and bright reflections are present on the conjunctiva. These phenomena sometimes disturb the image processing in the PR1000.

Cover tests generally are regarded as the best way to diagnose strabismus accurately, although they do require that the patient fixate a target continuously. In these tests, the lower limit of observable change of the eye position with the naked eye has been reported to be 2 PD or more under ideal conditions. Yet, the limit can deteriorate even further when there is error in prism positioning, misinterpretation of ambiguous fixation eye movements, or both. Considering that, we conclude that the precision of the video-based Hirschberg test is comparable to that of the PACT under clinical conditions.

The reproducibility of the video-based Hirschberg measurement was excellent regardless of the subject’s age group, and we think we can apply this test for infants and young children. Using this test, we can determine whether the deviation is manifest. When a manifest strabismus is present, we can still examine the binocular fixation pattern. These clinical assessments are important in evaluating and following patients with strabismic amblyopia until they are old enough to take the Snellen visual acuity measurement.

The difference of the reproducibility between the horizontal and vertical measurements was probably related to the differing resolution of the CCD image sensor for these two planes. In addition, an obstruction of the entrance pupil by the eyelashes or the eyelid may be a contributing factor, especially in infants and young children. The influence of this factor may be reflected by the outlying values observed in the reproducibility assessment for the vertical measurement. Hence, attention should be paid to such obstructions just before measurement.

The 95% limits of agreement between the Hirschberg and PACT values were poor. In the difference and mean plots of this comparative analysis, we found outlying values for some patients with intermittent exotropia and with accommodative esotropia. In the former group, the discrepancy between the two methods was perhaps caused by the intermittent nature of the strabismus; the Hirschberg test examines manifest deviation and the PACT manifest plus latent deviation with covering one eye covered. In the latter group, the deviation in those patients with hyperopia would be expected to vary significantly from one testing time to the next because spectacle correction could not be worn.

We found that the mean (± SD) Hirschberg ratio was 12.3° ± 1.2°/mm. The average value is in agreement with that shown previously on the basis
of laboratory research or theoretical extrapolation.\textsuperscript{3-6,9,10,18} In addition, Riddell and colleagues\textsuperscript{9} reported that the standard deviation of the Hirschberg ratio, which was obtained with the photographic method in 333 normal subjects, was $1.8^\circ$/mm. Considered together, their result and ours suggest the existence of considerable intersubject variation in the Hirschberg ratio: The standard deviation was approximately 10% of the mean value. If the individual Hirschberg ratio is not determined, the potential for as much as 20% systematic measurement error (95% confidence limits) should be taken into consideration. In the patients with large-angle strabismus, the intersubject variance in Hirschberg ratio can be another notable reason that the Hirschberg test and PACT values conflict. When highly quantitative data are required, such as in the preoperative planning for strabismus surgery, an individually estimated "personal" Hirschberg ratio should be used for the averaged Hirschberg ratio.

The angle between the pupillary axis and the line of sight is known as the angle lambda ($\lambda$). The angles $\lambda$ differ among subjects and, hence, can bias the results in the Hirschberg test. Although comparison of binocular and monocular fixating data is essential for discriminating between true strabismus and the angle $\lambda$, there is a trade-off between this theoretical rigidity and the ease of clinical application. However, the angles $\lambda$ have been reported to be similar for an individual, except in instances in which there are gross anatomic differences, such as marked anisometropia or unilateral retinopathy of prematurity.\textsuperscript{5,10,20} Accordingly, we regarded the corneal reflex asymmetry between the two eyes as the strabismic deviation in this study.

Finally, the apparatus described herein originally was not designed for examination of strabismus, and it does not necessarily have mechanical specifications suitable for this purpose. Accordingly, some improvements in hardware and software design should be made to adapt it for use in various clinical applications, such as optical correction and very large-angle strabismus. The systematic measurement error caused by the intersubject variance in Hirschberg ratio is not insignificant in terms of the quantitative analysis. However, the current study verified that the video-enhanced Hirschberg test affords good reproducibility and ease of application under actual clinical conditions. As long as it is used for specialized purposes with consideration of its advantages and disadvantages, this test will continue to serve as an invaluable tool.

**Key Words**

Hirschberg test, image processing, infant, ocular alignment, strabismus

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