GRAPHIC ANALYSIS OF PARALYTIC STRABISMUS WITH THE
LANCASTER RED-GREEN TEST

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We used the Lancaster red-green test to monitor changes in ocular alignment in patients with paralytic strabismus. By inferring the position of the right eye and that of the left eye at many different positions of gaze and then plotting the data on a graph, one can derive a static eye position curve. The location of the curve relative to the line depicting normal ocular alignment (orthophoria) indicates whether there is an esodeviation or an exodeviation. The slope of a line drawn tangent to the curve indicates, for that particular point, whether the deviation is concomitant or not and which eye is relatively weak or restricted and by how much. This graphic technique provides a simple, sensitive, and quantitative measure of ocular alignment that may be especially useful for detecting subtle changes in the relative positions of the two eyes. This method may be a useful adjunct in the planning and evaluation of therapy for patients with paralytic strabismus.

The Lancaster red-green test is used to assess ocular alignment in patients with paralytic strabismus. It is a binocular, dissociative, subjective test. The patient wears spectacles with a red filter in front of one eye and a green filter in front of the other. Each eye can then be stimulated separately, one with a red light and the other with a green light. The lights are projected onto a screen in front of the patient. The positions of the eyes are inferred from the positions of the lights on the screen as the patient moves one of the lights until it appears to be superimposed upon the other. Conventionally, measurements are made in the nine diagnostic positions of gaze, and the results are recorded on a grid to show the relative positions of the eyes.

We have developed a new way of representing and analyzing the data obtained from the Lancaster red-green test. We inferred the positions of the right eye and those of the left eye at many positions across the horizontal (or vertical) meridian and then plotted the results on a graph. The curve engendered from the data points then reflects the relative ability of the respective yoke muscles to rotate the globes. This graphic technique provides a quantitative measurement of ocular alignment from which one may infer the mechanical forces underlying an ocular misalignment.

The potential usefulness of this graphic technique in the diagnosis and management of paralytic strabismus was shown by the examples of several patients with
weakness of the lateral rectus muscle. We demonstrated the sensitivity of this technique by documenting the emergence of a small hypertropia in a normal subject after prolonged, monocular viewing.

SUBJECTS AND METHODS

The Lancaster red-green test was performed in a dark room. The subject sat 1 m away from a tangent screen with his head immobilized by a chinrest. The subject wore a red filter over the right eye and a green filter over the left eye and held a flashlight covered with a red filter in the right hand.

The examiner controlled the movement of a flashlight with a green filter and shone its light at various locations on the horizontal (or vertical) meridian of the tangent screen at approximately 5- to 8-degree intervals. At each position, the subject fixated the green target with the left eye and moved the red light in an attempt to superimpose it upon the green one. To keep the accommodative effort relatively constant, the subject was instructed to focus on the red grid pattern of the tangent screen visible only to the eye viewing with the green filter. We also performed the test with the green filter over the right eye and the red filter over the left eye in one subject and obtained the same results.

We recorded the positions of both lights. Each test point was sampled three to five times and a static eye position curve was obtained by plotting the mean of the measurements of the position of the right eye on the vertical axis vs the position of the left eye on the horizontal axis. We took the point at which the eye was pointig toward a target aligned with the nasion as the zero position. Therefore, because the eyes were actually separated by 6 or 7 cm, viewing a target at infinity, for example, resulted in apparent exophoria although the eyes were actually perfectly aligned.

The main sources of error in the Lancaster red-green test include inadequate immobilization of the head, fluctuations in the state of convergence (the result, for example, of a change in accommodation), suppression of images seen by one eye, and subjective superimposition of the red and green images when both images are not actually located on the fovea of each eye (anomalous retinal correspondence).

The state of accommodation, however, can be controlled when there is a grid upon which the patient is encouraged to focus. Fluctuations in accommodation and, consequently, vergence increase the variability of measures of horizontal deviations. Our average standard deviation, however, in a group of six patients with paralytic strabismus was only about 0.75 degrees. Monocular suppression and anomalous retinal correspondence are usually confined to patients with strabismus acquired early in life and were not encountered in our study.

RESULTS

Figure 1 shows the results of the Lancaster red-green test in two patients with right lateral rectus muscle palsy, one with short-term (less than one week in duration) and the other with long-term (about 18 months) posttraumatic palsy. Each patient showed the typical pattern of a loss of the contribution of forces from one lateral rectus muscle. On right gaze, in the direction of action of the paretic muscle, the data points increasingly deviate from the solid (orthophoria) line as the ocular deviation—an esodeviation—increases. For example, when the left (sound) eye was brought 40 degrees to the right, the patient with short-term palsy could bring his right (paretic) eye to 4 degrees left (esodeviation of about 44 degrees), whereas the patient with long-term palsy could only bring his right eye to 13 degrees left (esodeviation of about 53 degrees). Even with maximum
effort during ductions, with the paralyzed eye viewing, neither patient could abduct his right eye beyond the midline.

In addition to the ocular deviation, the relative difference in the ability of each eye to rotate the globe can be inferred by connecting the data points to produce a static eye position curve and then measuring the slope of a line drawn tangent to the curve. Normally the slope should be 1.0 if the abilities of the yoke muscles to rotate the globe are equal. For example, the solid (orthophoria) line has a slope of 1.0. In our patients, on right gaze, the slope of the static eye position curve was low and approached zero as the right eye reached a position beyond which it could not be abducted further. On straight-ahead gaze (left eye at 0 degrees) the slope of the curve was about 0.5. This indicated that at this position much more innervation must be sent to rotate the right eye a certain number of degrees than to rotate the left eye the same number of degrees. On left gaze, where the forces of the right lateral rectus muscle contributed less to holding the eye in position, the data points were closer to the solid (orthophoria) line and the esodeviations diminished. Similarly, the slope of the static eye position curve in left gaze was closer to 1.0.

There was, however, one important difference between the two patients. The data points of the patient with the longstanding lateral rectus muscle palsy were everywhere offset from the solid (orthophoria) line. Even in far left gaze with, for example, the left eye 30 degrees to the left, there was an esodeviation of about 15 degrees. This reflected a secondary contracture of the right medial rectus muscle, a finding later confirmed at surgery by a forced duction test.

Figure 2 illustrates the effects of muscle surgery in the patient with the long-term right lateral rectus muscle palsy. The patient underwent an 8-mm recession of the right, medial rectus muscle and an 11-mm resection of the right lateral rectus muscle. In the immediate postoperative period the patient's static eye position curve crossed the solid line near the primary position, indicating good ocular alignment in the straight-ahead position. The data points immediately diverged, however, from the solid

![Diagram](image-url)

Fig. 2 (Zee and associates). Effects of surgery (right lateral rectus muscle recession and right medial rectus muscle resection) on a patient with long-term right lateral rectus muscle palsy. Data points are for 2 preoperative (open triangles), immediately (18 hours) postoperative (solid triangles), and 16 days postoperative (squares) tests. Positive numbers are for rightward positions (R) and negative numbers for leftward position (L).
(orthophoria) line as the left eye was moved into the left or right field of gaze. On left gaze, for example, the patient's data points were above the solid line. This indicated an exodeviation that reflected the apparent medial rectus muscle weakness created by the surgical recession. For example, with the left eye at 30 degrees to the left, the right eye was about 15 degrees to the left, indicating an exodeviation of about 15 degrees. Further, in left gaze the slope of the static eye position curve was less than 1.0, reflecting the new right medial rectus muscle weakness. In right gaze, the old right lateral rectus muscle weakness was shown by the persistent esodeviation and reduced slope of the static eye position curve.

Sixteen days later the orbital position at which the eyes were aligned (orthophoria) had drifted to the left by about 15 degrees. The static eye position curve still showed persistent weakness of the right medial and right lateral recti muscles. The data points remained above the solid line in left gaze and below the line in right gaze and the slopes were less than 1.0 in both left and right gaze. About 15 degrees to the left, however, there was a region approximately 10 degrees wide at which the data points fell on the solid (orthophoria) line and the static eye position curve had a slope of 1.0. These rather subtle changes in ocular alignment were easily demonstrated and quantified with the Lancaster red-green plots.

Figure 3 shows the sensitivity of the Lancaster red-green test. A normal subject wore a patch over his right eye for 116 hours, after which vertical ocular alignment was assessed. For these graphs, five measurements were taken at each position; the average standard deviation of the means was only about 0.25 degree. After the period of monocular viewing there was a small noncomitant right hypertropia (the subject experienced vertical diplopia), with the deviation maximum (about 1.5 degrees) at about 10 to 20 degrees of upward gaze (Fig. 3, left). When the patch was left off and the test repeated three hours later, the vertical diplopia had disappeared and

![Fig. 3 (Zee and associates). The effect of prolonged monocular occlusion upon vertical ocular alignment in a normal subject. Left. After 116 hours of monocular viewing (right eye patched) there was a small noncomitant right hypertropia. The deviation was noncomitant. Right. A repeat Lancaster red-green test three hours after patch removal showed a smaller, essentially comitant, right hypertropia.](image-url)
only a small (about 0.6 degree), essentially concomitant, right hyperphoria was apparent (Fig. 3, right). In this case, we used the Lancaster red-green test to quantify a small, nonconcomitant increase in oculomotor misalignment brought out by prolonged monocular viewing.

**Discussion**

Figure 4 shows a summary scheme for reading the graphs generated from the Lancaster red-green test for horizontal deviations. The plot reflects only the relative ability of the respective yoke muscles to rotate the globes. For example, if points fall in the esodeviation portion of the graph, for a given point the lateral rectus muscle of one eye is applying or able to apply less force to rotate the globe than is the medial rectus muscle of the other eye. Whether or not there is actual muscle weakness (or restriction) and, if so, which eye is relatively weaker (or more restricted) can be inferred from the slope of the static eye position curve. Provided the data are plotted with left eye positions on the horizontal axis and right eye positions on the vertical axis, the value of the slope of a line drawn tangent to a curve connecting the points indicates which eye is relatively weaker or restricted. Slopes greater than 1.0 indicate relative left eye muscle weakness or restriction and slopes less than 1.0 indicate relative right eye muscle weakness or restriction. If the slope is equal to 1.0, then both yoke muscles are equally able to rotate the globes at that point on the graph. If, in a range of eye positions, the static eye position curve has a slope of 1.0 but is offset from the solid line, then a concomitant strabismus is present. In the case of a pure restriction without muscle weakness the slope of the eye position curve should be close to 1.0 until the eye meets the mechanical restriction at which the slope should change (and the ocular misalignment should increase) as further rotation of the globe becomes difficult or impossible.

The potential usefulness of this technique is perhaps best illustrated by comparing the test results in the postoperative period after corrective strabismus surgery (Fig. 2) and in the periods before and after prolonged monocular viewing (Fig. 3). In the case of the muscle palsy, surgery had produced normal alignment for straight-ahead viewing. The immediate postoperative static eye position curve crossed the solid (orthophoria) line at about primary position. The realignment of the eyes made fusion possible after surgery and produced good stereoscopic vision. Two weeks later, however, the orbital position at which the eyes were aligned had drifted by about 15 degrees to the left and the patient developed a head turn to keep the eyes in a position in which fusion was possible. However, the patient had a range of eye positions of at least 10 degrees (from 10 to 20 degrees left) in which the eyes were perfectly aligned. This subtle change was easily appreciated from the plot of the
data from the Lancaster red-green test. Similarly, the subtle increase in the hyperdeviation of a normal subject after prolonged monocular viewing was easily detected and quantified with the Lancaster red-green test. These changes in ocular alignment after surgery or after restoration of binocular viewing can be related to adaptive mechanisms that act to keep the eyes aligned over a wide range of orbital positions, to maintain Hermg’s law of equal innervation, and to assure concomitance.

REFERENCES


