Comparison of Methods for Measuring Cyclodeviation

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• PURPOSE: To compare the double-Maddox rod test with other methods of measuring cyclodeviation
• DESIGN: Retrospective cohort study.
• METHODS: We retrospectively identified 153 adults in a clinical practice with cyclodeviation assessed using double-Maddox rods, of whom 105 were also assessed using fusible synoptophore targets, 73 using nonfusible synoptophore targets, 118 using single-Maddox rod, and 43 using fundus photography. Relationships between double-Maddox rod and other tests were evaluated by calculating mean differences with 95% confidence intervals (CI), intraclass correlation coefficients (ICC), and Bland-Altman plots with linear regression.
• RESULTS: Synoptophore cross-in-circle targets and the largest (of right or left) single-Maddox rod values were similar to double-Maddox values (mean differences: -1.2° and 0.1°, respectively; ICC: 0.79 and 0.82, respectively). Synoptophore house targets measured less excyclodeviation (mean difference: -2.7°; ICC: 0.71). Mean summed single-Maddox rod values were somewhat similar to double-Maddox values (mean difference: 1.5°; ICC: 0.85), but differences increased with greater cyclodeviation ($r^2 = 0.2678$; $P < .001$). Fundus photographs showed large, uncorrelated differences compared with double-Maddox rod test, when summing right and left eyes and when using the largest of right or left (mean differences: 12.2° and 6.2°; ICC: -0.02 and 0.21, respectively), and differences increased with greater cyclodeviation ($r^2 = 0.4094$; $P < .001$ and $r^2 = .1143$; $P = .03$, respectively).
• CONCLUSIONS: There was good agreement between double-Maddox and the largest single- Maddox test values and synoptophore cross-in-circle targets but poorer agreement with other tests. Further study is needed to understand which measurements best reflect true cyclodeviation and relationships with symptoms. (Am J Ophthalmol 2021;224:332–342. © 2020 Elsevier Inc. All rights reserved.)

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REPRESENTATIVE MEASUREMENTS OF CYCLODEVIATION are critical to the diagnosis and management of many types of strabismus. Both objective and subjective measurement methods are used in clinical practice, each representing different aspects of cyclodeviation.[1,2] Objective measurements such as assessment of the fundus (by photography or direct observation) represent the anatomic, torsional position of the eyes.[2] Subjective measurements, such as the commonly used double-Maddox rod (DMR) test, reflect the patient's perception of cyclodeviation, incorporating any sensory adaptation and cyclofusion.[2] Most clinicians base management decisions on the magnitude of cyclodeviation as measured using a subjective method, but there are few studies comparing different methods, particularly evaluating the single-Maddox rod (SMR) test, which has garnered recent interest,[3,4] and it remains unclear whether there are systematic differences between tests of which clinicians should be aware. Therefore one aim of the present study was to compare the commonly used DMR test with alternative subjective methods, including the synoptophore (using fusible and nonfusible targets) and the SMR tests. Nevertheless, some providers prefer objective evaluation of cyclodeviation by using the anatomic position of the fundus to guide management decisions.[5,6] Therefore, while acknowledging that differences between subjective DMR measurements and objective fundus measurements would be expected,[1,2] the magnitude and nature of these differences were investigated further in the present study.

METHODS

INSTITUTIONAL REVIEW BOARD APPROVAL FOR THIS retrospective study was obtained from the Institutional Review Board at the Mayo Clinic (Rochester, Minnesota, USA). All procedures and data collection were conducted in a manner compliant with the Health Insurance Portability and Accountability Act, and all research procedures adhered to the tenets of the Declaration of Helsinki.

• PATIENTS: Adult patients attending a strabismus clinic at a tertiary referral center, with measurements of cyclodeviation by DMR and at least 1 other testing method, at a single examination, were retrospectively identified from clinical databases. To include data across a wide range of

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cyclodeviation, all types of strabismus were included, and previous surgery was allowed; patients were not required to have symptomatic torsional diplopia. To maximize the number of patients for each comparison, results of the first examination at which the patient underwent measurements of cyclodeviation by DMR and another testing method were included. A single patient could be included for more than 1 comparison (on the same or different visits), whereas another might have been included only once (for 1 comparison).

• **DOUBLE-MADDOX ROD:** Double-Maddox rod testing was performed as described previously,[7] fixing a light source (Finoff Transilluminator, Welch Allyn, Milwaukee, Wisconsin, USA) at 0.3 meters, with the red lens in front of the right eye and the white lens in front of the left eye, under standard examination room lighting conditions. The lenses were offset obliquely from either side (nonstandardized), and the patient was asked to adjust 1 knob of the trial frame at a time until the 2 lines appeared horizontal. The examiner recorded the cyclodeviation as indicated on the trial frame (the 0-cyclodeviation position having been manually marked on the lens frame), estimating to the nearest degree between the 5-degree markings. Net cyclodeviation was calculated as the sum of the right eye plus the left eye. When the patient could not distinguish the 2 lines, it has been this clinic's standard practice to use a small amount of vertical prism to enable visualization of both lines. In some patients, DMR measurements were repeated a total of 3 times (without other testing in between), and the average of the 3 measurements was calculated. Because taking the average of 3 measurements provides a more representative measurement, results of the first examination with 3 DMR measurements were included for each comparison when these data were available.

• **SYNOPTOPHORE:** The magnitude of cyclodeviation was assessed on the synoptophore by using both fusible targets (eg, house slides: F 9/10, subtending 6.5°) and nonfusible targets (eg, large cross-in-circle slide: A 17/18; both slide sets are available from www.haag-streit.com). The patient viewed the targets straight ahead. For each set of slides, 1 target was set at zero (the circle for the cross-in-circle targets), and the subjective angle of deviation was corrected by asking the patient to adjust the other target using the movable synoptophore arm horizontally to approximate the targets as closely as possible. Then, a certified orthoptist corrected any vertical and/or torsional misalignment, as directed by the patient. For the house slides, when the 2 images are aligned and fused, the house should appear as a single image with both trees present. For the cross-in-circle slides, the end point is when the cross is aligned in the center of the circle. The subjective angle of cyclodeviation for each set of slides was recorded in degrees as indicated on the torsion dial.

• **SINGLE-MADDOX ROD TESTING:** For SMR testing, a single red Maddox rod lens was mounted in a trial frame in front of the right eye and offset at an oblique angle while the left eye remained unoccluded. The rods were offset from either side in a nonstandardized fashion, but the authors' typical practice was to perform the first measurement with the offset from the excyclo side, the second from the incyclo side, and the third from the excyclo side. While viewing a light source straight ahead at 0.3 meters distance under standard examination room lighting conditions, the patient was asked to adjust the knob on the trial frame until the red line appeared horizontal. The examiner then recorded the number of degrees (to the nearest degree) as indicated on the trial frame. This process was repeated a total of 3 times for the right eye and the average of the 3 measurements was calculated. The white Maddox rod lens was then placed in front of the left eye while the right eye was unoccluded. The same process of measuring cyclodeviation was repeated 3 times for the left eye, and the average of the 3 measurements was calculated. For analysis, the largest of the right or left eye measurement was used (similar to the method used by Almog and associates,[8] who analyzed each eye separately), and the sum of right eye and left eye measurements was also used (as reported by Flodin and associates[4]).

• **FUNDUS PHOTOGRAPHY:** Fundus photographs were taken using the Topcon 50DX machine (Topcon Medical Systems, Oakland, New Jersey, USA) with the internal fixation stick to standardize fixation, with the nonphotographed eye occluded. Photographs were then imported into Photoshop software (Adobe, San Jose, California, USA), where the angle between the center of the optic nerve and the bottom of the internal fixation stick was calculated for each eye using the ruler tool. Excyclodeviation was assigned a positive value and incyclodeviation a negative value. Fundus values were analyzed as the sum of measurements from each eye[9] and also by using the largest of right eye or left eye measurements.[1]

• **ANALYSIS:** Mean DMR values were calculated from the average of 3 measurements in a single examination when available but otherwise from single measurements. All SMR values were the average of 3 measurements at a single examination. For synoptophore and fundus photographs, mean values were calculated from single measurements.

For each test of cyclodeviation, relationships with DMR were assessed by calculating the mean difference and 95% confidence intervals (CI). In addition, Bland-Altman plots were created to represent the variability of the differences and half widths of the 95% limits of agreement, with associated 95% CIs on the limits of agreement. Linear regression analyses were performed to quantify any relationship of the differences between methods and the average of the two measurement methods. Also, intraclass correlation coefficients (ICC) were calculated to assess agreement between measurements, where a coefficient of >0.80

TABLE 1. Agreement between Double Maddox Rod and Alternative Methods of Measuring Cyclodeviation

Comparison	n	Mean DMR degrees (range)	Mean Alternative Method degrees (range)	Difference degrees (95% CI)	95% LOA Half-Width degrees (95% CI)	ICC (95% CI)	Bland-Altman Regression r^2 (*P* Value)
DMR vs. synoptophore cross	73	6.4 (−7.7 to 26.0)	5.2 (−6.0 to 30.0)	−1.2 (−2.1 to −0.4)	6.9 (5.5 to 8.3)	0.79 (0.68 to 0.86)	0.0032 (.63)
DMR vs. synoptophore house	105	6.1 (−15.0 to 24.0)	3.4 (−14.0 to 28.0)	−2.7 (−3.4 to −2.0)	7.0 (5.9 to 8.2)	0.71 (0.60 to 0.79)	0.0030 (.58)
DMR vs. single Maddox rod (largest)	118	3.3 (−10.0 to 21.3)	3.4 (−7.0 to 21.3)	0.1 (−0.5 to 0.7)	6.1 (5.1 to 7.0)	0.81 (0.74 to 0.87)	0.0154 (.18)
DMR vs. single Maddox rod (summed)	118	3.3 (−10.0 to 21.3)	4.8 (−12.0 to 26.5)	1.5 (0.9 to 2.0)	5.7 (4.8 to 6.6)	0.85 (0.80 to 0.90)	0.2596 (<.01)
DMR vs. fundus photograph (summed)	43	4.6 (−7.7 to 21.3)	16.7 (−9.0 to 35.0	12.1 (9.5 to 14.6)	16.4 (12.0 to 20.9)	−0.02 (−0.31 to 0.28)	0.4094 (<.01)
DMR vs. fundus photograph (largest)	43	4.6 (−7.7 to 21.3)	10.7 (−10.0 to 26.0)	6.1 (3.9 to 8.2)	13.7 (7.9 to 19.4)	0.20 (−0.10 to 0.47)	0.1132 (.03)
DMR vs. fundus photograph (summed) when recent onset	13	6.9 (−7.3 to 21.3)	18.2 (0.0 to 35.0)	11.3 (7.5 to 15.1)	12.2 (5.8 to 18.7)	0.30 (−0.26 to 0.71)	0.3893 (.02)
DMR vs. fundus photograph (largest) when recent onset	13	6.9 (−7.3 to 21.3)	12.1 (−2.0 to 26.0)	5.2 (2.1 to 8.2)	9.9 (4.7 to 15.2)	0.55 (0.04 to 0.83)	0.0060 (.80)

CI = confidence interval; DMR = double Maddox rod test; ICC = intraclass correlation coefficient; LOA = limits of agreement.

indicated almost perfect agreement, >0.60-0.80 substantial agreement, and >0.4-0.6 moderate agreement. For each comparison, the mean difference and ICC were calculated in a constrained subgroup of patients with larger amounts of excyclodeviation (5° or more) to evaluate whether low-magnitude cyclodeviations (included in the overall analysis) might have artificially increased agreement and reduced differences between measurements.

In secondary analyses, fundus photographs were reanalyzed, including only those with strabismus of relatively recent onset (acquired within the 5 years preceding the examination). We also explored the potential effects of rod color on the magnitude of cyclodeviation, measured by DMR, because a previous study[10] reported that, in most patients, cyclodeviation localizes to the red rods, regardless of the affected eye. The mean value from the eyes with the red rod was compared with the mean value from the eyes with the white rod (from the first DMR measured in each patient), for patients with unilateral superior oblique palsy, analogous to the previous study by Simons and associates.[10]

RESULTS

• **PATIENTS:** A total of 153 patients were studied (median age: 62; age range: 18-87 years of age) who had a DMR measurement and at least 1 other measurement of cyclodeviation performed in a single clinical examination. A total of 73 patients had DMR measurements and the synoptophore cross-in-circle target; 105 patients had DMR tests and the synoptophore house target; 118 had DMR and SMR; and 43 had DMR measurements and examination by fundus photographs. Sixty-six patients were included in more than 1 analysis. Strabismus type was restrictive in 45, neurogenic in 66, childhood onset or decompensated in 31; associated with epiretinal membrane in 7; and in 4 patients, there was epiretinal membrane but no strabismus (evaluated in the strabismus clinic as part of a workup for epiretinal membrane). Overall, cyclodeviation ranged from 15° incyclodeviation to 24° excyclodeviation at the first DMR measurement.

• **DOUBLE-MADDOX ROD VERSUS SYNOPTOPHORE CROSS-IN-CIRCLE TARGET:** There was good agreement between the DMR and synoptophore cross-in-circle targets (n = 73; ICC: 0.79). The mean synoptophore cross-in-circle value was slightly less than the mean DMR value (mean difference: −1.2°; half-width of the 95% limits of agreement, 6.9°) (Table 1, Figure 1). There was no relationship between magnitude of differences and average of the 2 methods by linear regression (P = .63) (Table 1, Figure 1). Forty-five of 73 patients had 5° or more of excyclodeviation. In that subgroup, the mean difference was −2.0°, and the ICC was 0.61 (Table 2).

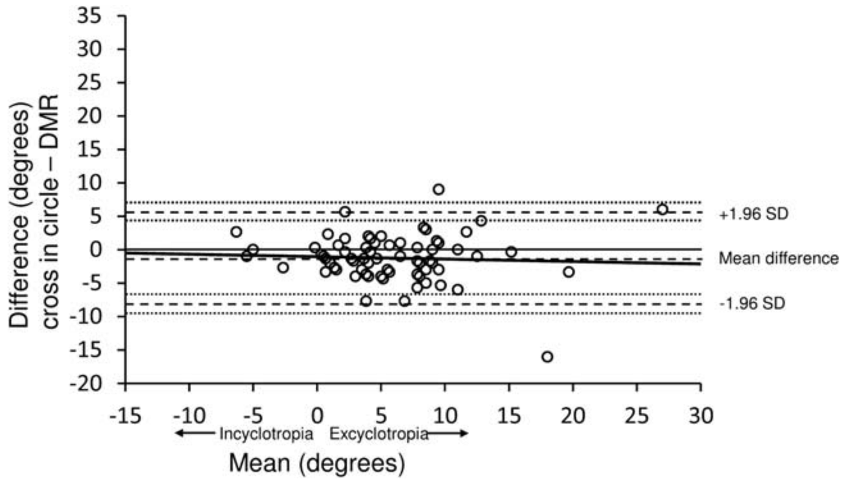

FIGURE 1. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and the synoptophore cross-in-circle target. The mean of the differences was -1.2° (middle dotted line), and the half-width of the 95% limits of agreement was 6.9°. Linear regression showed no relationship between magnitude of differences and average of the 2 methods: $r^2 = 0.0032$; $P = .63$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

• **DOUBLE MADDOX ROD VERSUS SYNOPTOPHORE HOUSE TARGETS:** There was good agreement between the DMR and synoptophore house target (n = 105; ICC: 0.71) (Table 1). The mean synoptophore house value was somewhat less than the mean DMR value (mean difference: -2.7°; half-width of the 95% limits of agreement: 7.0°) (Table 1, Figure 2). There was no relationship between magnitude of differences and average of the 2 methods by linear regression ($P = .58$) (Table 1, Figure 2). Sixty-eight of 105 patients had 5° or more of excyclodeviation. In that subgroup, the mean difference was -3.7°, and the ICC was 0.47 (Table 2).

• **DOUBLE-MADDOX ROD VERSUS LARGEST SINGLE-MADDOX ROD:** Across the 118 patients with measurements of DMR and SMR, there was excellent agreement when using the largest of right and left SMR values (ICC: 0.81) (Table 1). The mean DMR value was very similar to the mean SMR (mean difference: 0.1°; half-width of the 95% limits of agreement: 6.1°) (Table 1, Figure 3). There was no relationship between the magnitude of differences and average of the 2 methods by linear regression ($P = .18$) (Table 1, Figure 3). Forty of 118 patients had 5° or more of excyclodeviation. In that subgroup, the mean difference was -1.4°, and the ICC was 0.71 (Table 2).

• **DOUBLE-MADDOX ROD VERSUS SUMMED SINGLE-MADDOX ROD:** When summing right and left SMR values (n = 118), mean SMR was somewhat greater than mean DMR, with a mean difference of 1.5° (Table 1, Figure 4). The half-widths of the 95% limits of agreement were 5.7° (Table 1, Figure 4). Although there was good overall agreement between tests (ICC: 0.85) (Table 1), linear regression analysis showed progressively greater differences between DMR and SMR measurements with increasing cyclodeviation ($P < .001$) (Table 1, Figure 4). This was reflected in the 40 patients with 5° or more of excyclodeviation, where the mean difference was 2.4°, and the ICC was 0.69 (Table 2).

• **DOUBLE MADDOX ROD VERSUS SUMMED FUNDUS PHOTOGRAPH:** There was poor agreement between the DMR and summed fundus photograph values (n = 43; ICC: $-.02$) (Table 1), with the mean summed fundus value markedly more (16.7) than the mean DMR value (4.6; mean difference: 12.1°; half-width of the 95% limits of agreement: 16.4°) (Table 1, Figure 5). Linear regression showed increasing differences between measurements with increasing magnitude of cyclodeviation ($P < .001$) (Table 1, Figure 5). Nineteen of 43 patients had 5° or more of cyclodeviation. In that subgroup, the mean difference between tests was 12.2°, and the ICC was $-.22$ (Table 2).

• **DOUBLE MADDOX ROD VERSUS LARGEST CYCLODEVIATION BY FUNDUS PHOTOGRAPH:** When analyzing the larger of right or left eye fundus values, agreement was poor (ICC: .20) (Table 1), and linear regression analysis showed an increase in differences between testing methods with increasing magnitude of cyclodeviation ($P = .03$) (Table 1, Figure 6). The mean of the larger of right and left values was markedly greater than the mean DMR value (10.7° vs. 4.6°; mean difference 6.1°;

half-width of the 95% limits of agreement: 13.7°) (Table 1, Figure 6). In the 19 patients with 5° or more of cyclodeviation, the mean difference was 4.1°, and the ICC was .10 (Table 2).

• DOUBLE-MADDOX ROD VERSUS FUNDUS PHOTOGRAPHS IN A SUBGROUP WITH RECENT ONSET STRABISMUS: We continued to find poor agreement between summed fundus values and the DMR values (ICC: 0.30) (Table 1) in the subgroup of 13 patients with strabismus acquired within the previous 5 years. Mean fundus photograph values were markedly greater than mean DMR values (18.2° vs. 6.9°, respectively; mean difference: 11.3°; half-width of the 95% limits of agreement: 12.2°) (Table 1, Figure 7). In addition, linear regression analysis showed an increase in differences between testing methods with increasing magnitude of cyclodeviation (P = .02) (Figure 7).

We also continued to find poor agreement between the largest of right or left fundus values and DMR values in the subgroup with acquired strabismus (ICC: 0.55) (Table 2). The mean fundus value was still markedly greater than the mean DMR value (12.1° vs. 6.9°, respectively; mean difference: 5.2°; half-width of the 95% limits of agreement: 9.9°) (Table 1, Figure 8).

• COMPARING CYCLODEVIATION WITH RED VERSUS WHITE MADDOX RODS: Twenty-three patients had unilateral fourth nerve palsy (8 right eye and 15 left). The mean value from the eye with the red rod was surprisingly smaller (2.1° ± 3.4°) than the mean value from the eye with the white rod (5.4° ± 3.6°; mean difference: –3.3°; 95% CI: −6.1° to −.4°).

TABLE 2. Agreement between Double Maddox Rod and Alternative Methods of Measuring Ocular Torsion in Patients with 5 Degrees or More of Excyclodeviation

Comparison	n	Mean DMR degrees (range)	Mean Alternative Method degrees (range)	Difference degrees (95% CI)	95 % LOA Half-Width degrees (95% CI)	ICC (95% CI)	Bland-Altman Regression r^2 (P Value)
DMR vs. synoptophore cross	45	9.6 (5.0 to 26.0)	7.7 (0.0 to 30.0)	−2.0 (−3.2 to −0.8)	7.8 (5.8 to 9.9)	0.61 (0.39 to 0.77)	0.0300 (.25)
DMR vs. synoptophore house	68	9.2 (5.0 to 24.0)	5.5 (0.0 to 28.0)	−3.7 (−4.6 to −2.8)	7.6 (6.0 to 9.2)	0.47 (0.26 to 0.63)	0.1976 (<.001)
DMR vs. single Maddox Rod (largest)	40	8.9 (5.0 to 21.3)	7.6 (−3.0 to 21.3)	−1.4 (−2.3 to −0.4)	5.6 (4.1 to 7.2)	0.71 (0.52 to 0.84)	0.0038 (.70)
DMR vs. single Maddox Rod (summed)	40	8.9 (5.0 to 21.3)	11.3 (−0.5 to 26.5)	2.4 (1.2 to 3.5)	7.1 (5.1 to 9.1)	0.69 (0.48 to 0.82)	0.4464 (<.001)
DMR vs. fundus photograph (summed)	19	9.4 (5.3 to 21.3)	21.6 (−2.0 to 35.0)	12.2 (8.0 to 16.3)	16.9 (9.8 to 24.0)	−0.22 (−0.60 to 0.24)	0.5886 (<.001)
DMR vs. fundus photograph (largest)	19	9.4 (5.3 to 21.3)	13.5 (−4.0 to 26.0)	4.1 (1.1 to 7.2)	12.4 (7.2 to 17.6)	0.10 (−0.35 to 0.52)	0.2332 (.04)

CI = confidence interval; DMR = double Maddox rod test; ICC = intraclass correlation coefficient; LOA = limits of agreement.

DISCUSSION

WHEN COMPARING DIFFERENT MEASUREMENTS OF CYCLODEVIATION with those of the commonly performed DMR test, the synoptophore cross-in-circle target, and the largest of right or left eye SMR values, appeared almost equivalent to the DMR values. The other measurements studied (synoptophore house target, summed SMR, and fundus photographs) showed systematic and variable biases and should not be considered equivalent to or interchangeable with the DMR.

Excellent agreement was found between the DMR and nonfusible (cross-in-circle) synoptophore targets (ICC: 0.79), similar to the findings of Georgievski and Kowal[11] (reported ICC: 0.87). Nevertheless, DMR values were, on average, slightly greater than synoptophore cross-in-circle values (mean: 6.4 vs. 5.2°), again similar to the findings of Georgievski and Kowal,[11] although the differences were likely not clinically meaningful. Similar cyclodeviation values using the DMR and synoptophore cross-in-

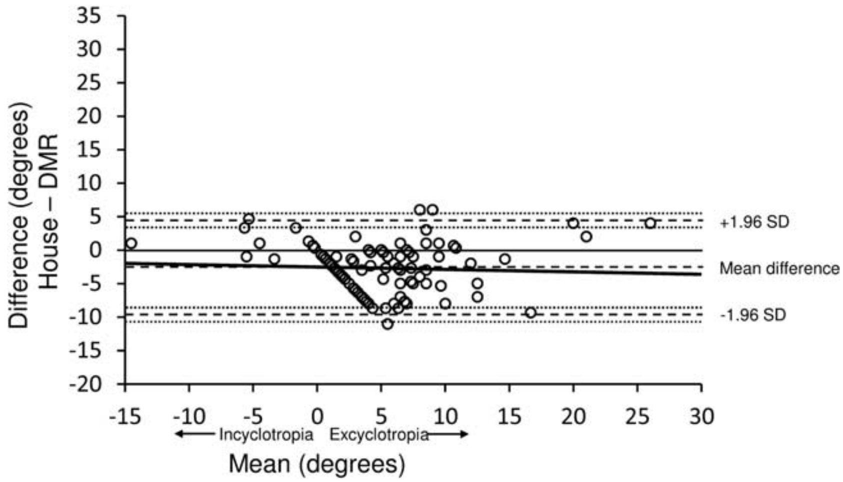

FIGURE 2. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and the synoptophore house target. The mean of the differences was -2.7° (middle dotted line), and the half-width of the 95% limits of agreement was 7.0°. Linear regression showed no relationship between magnitude of differences and average of the 2 methods: $r^2 = 0.0030$; $P = .58$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

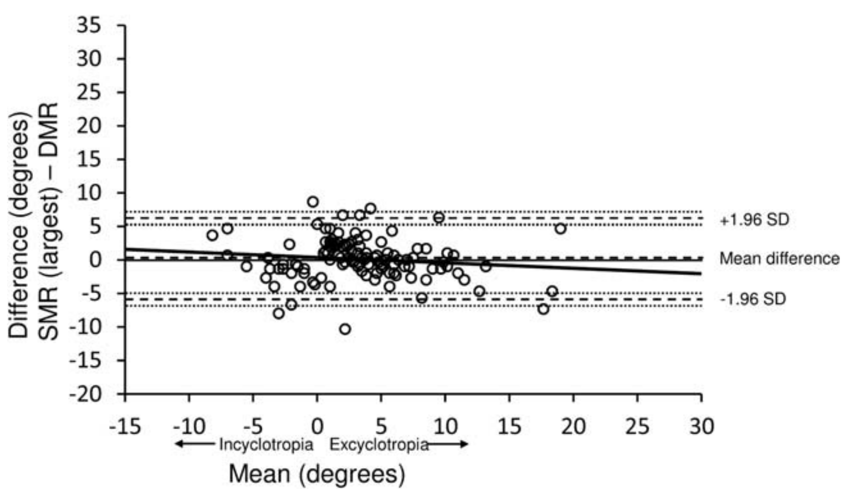

FIGURE 3. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and single-Maddox rod (largest of right- and left-eye values). The mean of the differences was 0.1° (middle dotted line), and the half-width of the 95% limits of agreement was 6.1°. Linear regression showed no relationship between magnitude of differences and average of the 2 methods: $r^2 = 0.0154$; $P = .18$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

circle targets would be expected because both tests present nonfusible targets and are fully dissociative.

The authors of the present study are not aware of previous studies comparing the DMR with fusible house targets on the synoptophore. It was expected that differences between the DMR and fusible house targets would be greater than those between the DMR and nonfusible cross-in-circle targets because the house targets allowed sensory fusion of images, resulting in a lower magnitude of deviation. This difference between fusible and nonfusible synoptophore targets highlights the importance of being cognizant of the specific type of target used when evaluating cyclodeviations using the synoptophore.

The SMR test has been proposed by previous investigators as a simpler alternative to the DMR, yielding equivalent values.[8] Almog and associates[8] performed testing with the SMR (each eye separately using only the red rods) and the DMR (red and white rods) in

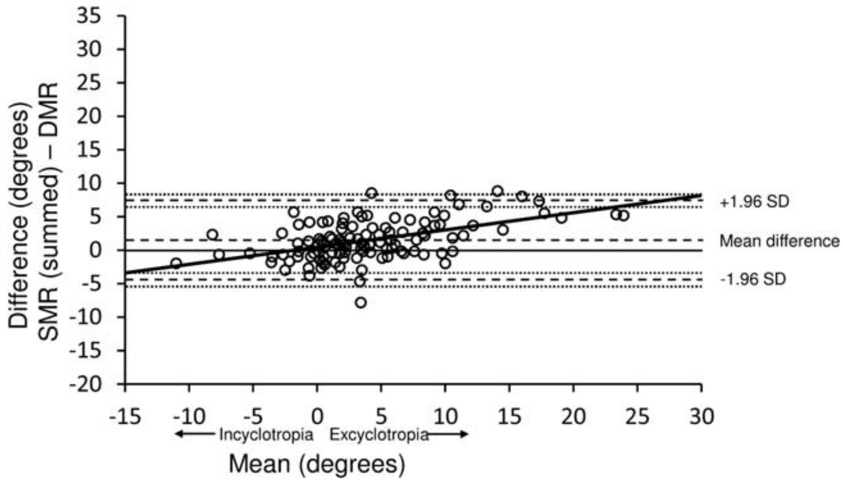

FIGURE 4. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and single-Maddox rod (right- and left-eye values summed). The mean of the differences was 1.5° (middle dotted line), and the half-width of the 95% limits of agreement was 5.7°. Linear regression showed progressively greater differences with increasing cyclodeviation: r^2 = 0.2596; $P < .001$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

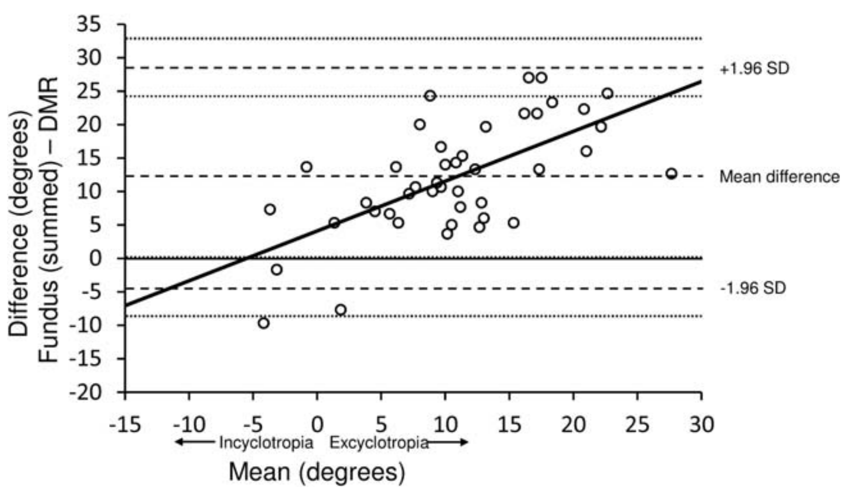

FIGURE 5. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and fundus photographs (right- and left-eye values summed). The mean of the differences was 12.1° (middle dotted line), and the half-width of the 95% limits of agreement was 16.4°. Linear regression showed progressively greater differences with increasing cyclodeviation: r^2 = 0.4094; $P < .001$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

48 patients with superior oblique palsy and found excellent agreement between tests: ICC: 0.88 using the SMR with reds rods in front of the affected eye and ICC: 0.85 with red rods in front of the unaffected eye. The present study used the largest of the right or left eye SMR values because in some patients it is difficult to know which is the affected versus the unaffected eye, and some patients have bilateral disease. Nevertheless, excellent agreement was also found (ICC: 0.81) when comparing the largest of the right or left SMR values with the DMR values.

We also compared the DMR to summed (right plus left eye) SMR values, because this approach has been described by Flodin and associates.[3,4] While good agreement and a relatively low mean difference was observed, there was a significant bias, with the magnitude of differences increasing with progressively larger cyclodeviation. Such bias renders the summed SMR noninterchangeable with

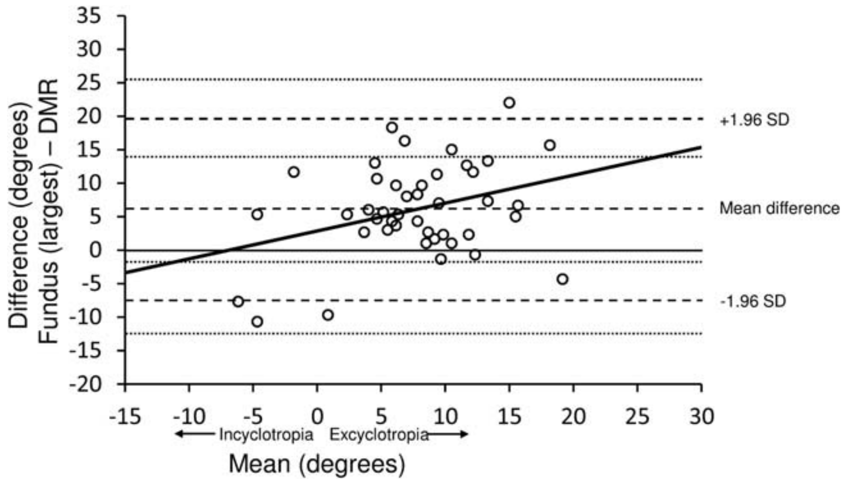

FIGURE 6. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and fundus photographs (largest of right- and left-eye values). The mean of the differences was 6.1° (middle dotted line), and the half-width of the 95% limits of agreement was 13.7°. Linear regression showed progressively greater differences with increasing cyclodeviation: $r^2 = 0.1132$; $P = .03$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

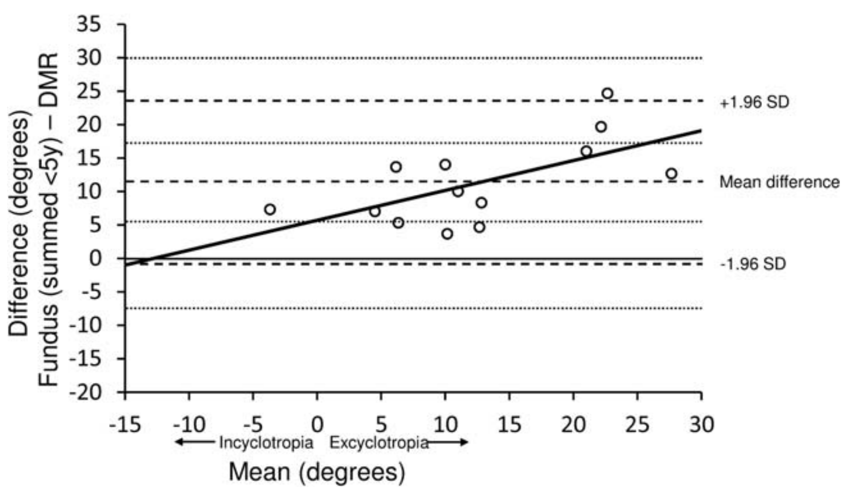

FIGURE 7. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and fundus photographs (right- and left-eye values summed) in 13 patients with onset of strabismus within the past 5 years. The mean of the differences was 11.3° (middle dotted line), and the half-width of the 95% limits of agreement was 12.2°. Linear regression showed progressively greater differences with increasing cyclodeviation: $r^2 = 0.3893$; $P = .02$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

the DMR because, at larger magnitudes of cyclodeviation, the summed SMR often results in a much larger value than the DMR. It is important to note that although previous studies may have implied that the DMR and summed SMR are interchangeable, citing similar 95% limits of agreement for repeated measurements[4], similar 95% limits of agreement should not be interpreted to be the same as good agreement or a strong correlation between 2 testing methods.

Some authors believe anatomic torsion, determined by objective evaluation of the fundus, is more important than subjective evaluation when managing cyclovertical strabismus[5,6]; therefore, the authors of the present study were interested to quantify the magnitude of differences using

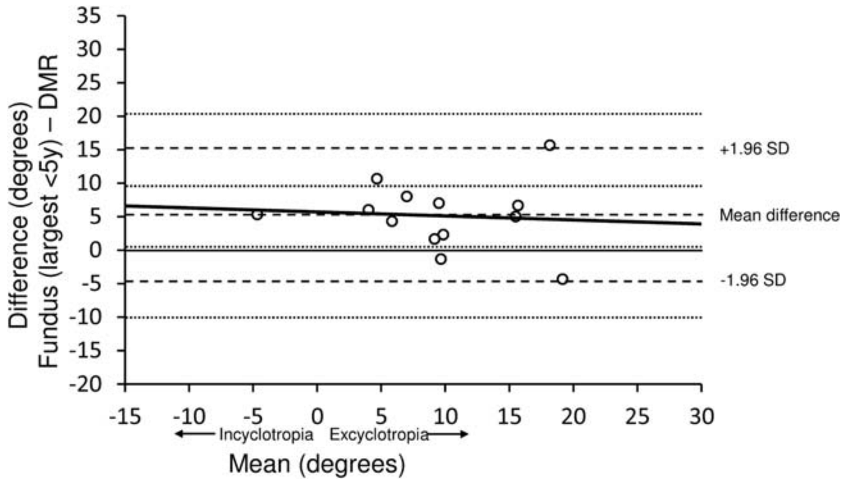

FIGURE 8. Bland-Altman plot shows the 95% limits of agreement for the differences between the double-Maddox rod and fundus photographs (largest of right- and left-eye values) in 13 patients with onset of strabismus within the past 5 years. The mean of the differences was 5.2° (middle dotted line), and the half-width of the 95% limits of agreement was 9.9°. Linear regression showed no relationship between magnitude of differences and average of the two methods: $r^2 = 0.0060$; $P = .8$. Fine-dotted lines indicate 95% confidence intervals on limits of agreement.

these approaches more carefully. Large mean differences were found between fundus photographs and the DMR (6.1° using the larger of right and left values and 12.1° when summing values) and considerable variability (half-widths of the 95% limits of agreement: 13.7° and 16.4°, respectively). Differences between these methods can be explained in part by the fact that normal is not zero degrees, but includes a wide range of values, corresponding to the fovea being in line with the lower one-third of the disc (a 9-degree range by some reports,[2] or an average of 7.25° with a range of 0.6-12.2° below the horizontal meridian by others[12]). Although it may seem appealing to account for "normal" to better represent fundus values, it is problematic given the wide range of normal values and the fact that one does not know where an individual patient started on that range before the onset of strabismus. Applying an average correction factor (eg, 7.25°) would result in less mean difference between measurements but would not reduce the variability across a population. A second explanation for differences between the DMR and fundus measurements is adaptation to childhood-onset strabismus,[13,14] a phenomenon somewhat confirmed in the present study in which better (although still suboptimal) agreement was found when evaluating a subgroup with recent-onset strabismus (ICC: 0.55, Table 1). The third explanation for differences between the DMR and fundus measurements is the presence or absence of sensory adaptation and/or cyclofusion.[2] Taken together, data from the present study confirm those of previous studies,[1,2] that objective measurements of anatomic torsion by fundus evaluation are not, nor would be expected to be, the same as subjective measurements of cyclodeviation. What remains unresolved is the question of which measurement should be used for guiding clinical decision making, that is, although most eye care providers use a subjective measurement, believing it more likely to reflect residual, uncompensated cyclodeviation and therefore symptoms, that view is challenged by those who believe the subjective measurement grossly underestimates the true cyclodeviation and, as a result, may lead to inadequate surgery.[5,6] Further study is needed to better understand the relationship between different torsional measurements and symptomatic cyclodeviation, as well as optimal surgical strategies to address such symptoms.

Because our overall analyses included many patients with low magnitude cyclodeviation, and such low values may artificially increase agreement between tests, the present authors repeated all analyses in a constrained subgroup of patients with 5° or more of excyclodeviation by initial DMR testing. Low-magnitude mean differences and substantial agreement continued to be found between the DMR and the synoptophore cross-in-circle targets and between the DMR and largest of right or left SMR. There was somewhat poorer (moderate) agreement between DMR and synoptophore house targets, but poor agreement and large differences continued to be found between the DMR and fundus photographs and between the DMR and summed SMR values.

This study explored differences between the amount of cyclodeviation measured using red rods versus white rods when performing the DMR test because previous studies[10] have reported that cyclodeviation is likely to localize to the red rods regardless of the affected eye. The present study was unable to confirm the findings of Simons and associates[10] that red rods elicit the larger cyclodeviation, even though a subgroup of patients with unilateral superior oblique palsy was analyzed, similar to the population studied by Simons and associates.[1] In fact, a number of patients were found to have greater deviation with the white rods, and neither the color of the rod nor the laterality of the superior oblique palsy was associated with a greater value in one eye or the other. The influence of rod color on the magnitude of measured cyclodeviation deserves further study in larger clinical populations.

There are some limitations to the present study. Not every patient had a complete set of data. Nevertheless, the authors believe there was sufficient sample size for a primary analyses comparing different testing methods to the DMR. Also other subjective methods of evaluating cyclodeviation such as the Lancaster red-green test were not included.[15] It would have been helpful to have a larger sample size with recently acquired strabismus in the subgroup analysis comparing fundus photographs and DMR. Fundus data were not analyzed by calculating the net difference between eyes, an approach used in some previous studies.[14,16] Although that method may be valid in acquired, unilateral strabismus, it is otherwise problematic, requiring assumptions that the unaffected eye represents the patient's baseline status prior to onset of strabismus and that this baseline status was the same in each eye. The present study was designed to evaluate differences between the DMR and other tests of cyclodeviation but did not address the question of which test was "best" or which was most likely to reflect symptoms. Such future studies should use a patient-reported measure of symptoms in subjects with primarily torsional strabismus. In addition, data were not collected to study the influence of type and laterality of strabismus, fixation with the affected versus unaffected eye, and chronicity. Other investigators have recommended using 2 red rods for DMR testing,[10] testing in a dark room,[2,10] or performing the SMR using the same color rod for each eye,[8] none of which was our standard clinical practice at the time of the study, and our results may have differed had we performed testing under those conditions. In addition, Maddox rod lenses were used on which the zero cyclodeviation position had been manually marked, and measurements might have been more accurate had lenses been used with that position premarked during manufacture.

In summary, when measuring subjective cyclodeviation, both the synoptophore cross-in-circle targets and the largest of right or left SMR values appear to provide measurements that are similar to those obtained with the DMR. Nevertheless, fusible synoptophore targets and summed SMR values differ from those of the DMR, suggesting these methods cannot be used interchangeably with the DMR. Objective evaluation of fundus photographs is useful for assessing anatomic torsion but needs to be interpreted in the context of a wide range of normal values. Not surprisingly, a high level of disagreement was found between fundus photographs and the DMR. Further study is needed to understand which measurement(s) best reflect the relationship with symptoms associated with torsion and their treatment.

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