Reevaluation of Current Prism Standards With Recommendations to Increase Accuracy in the Measurement of Strabismus

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• PURPOSE: **To critically evaluate the traditional standards for holding single prisms in measuring strabismus, with the specific goal being to increase the overall accuracy of clinical measurements.**
• DESIGN: **Reliability and validity analysis.**
• METHODS: **Using an analysis involving geometric optics, the effective prism power (EPP), measured in prism diopters (PD), was calculated for glass and acrylic prisms and was the main outcome measure. These results were also validated using optical bench measurements. No patients were involved.**
• RESULTS: **Plotting the calculated effective prism power as a function of rotational angle produced curves demonstrating that the frontal plane position lies along the flatter portions of the curves, while the Prentice position lies along the steeper portions of the curves. Calculated values of prism power for the standard clinical positions as well as the percentage errors from accepted standards were compared. Acrylic prisms can be held in the frontal plane position with acceptable amounts of error (<5%) for prisms up to 50 PD. Glass prisms are capable of producing significant errors for measurements much greater than 10 PD.**
• CONCLUSIONS: **The use of glass prisms as currently calibrated should be abandoned or at least limited to small measurements. Acrylic prisms produce acceptable errors if careful attention is given to their position. (Am J Ophthalmol 2019;198:130–135. © 2018 Elsevier Inc. All rights reserved.)**

PRISMS HAVE BEEN USED FOR CLINICAL MEASUREments in ophthalmology, such as in the setting of refraction and strabismus, for well over a century.[1,2] Discussions regarding prism manufacturing standards and how to describe or label them according to their power were held in the literature.[3] Over time, standards were developed for both acrylic (plastic) and glass (crown glass) prisms used in clinical practice for measurement of misalignments of the ocular axes.

Fundamentally, prisms are best described by their apical angle, A. The actual power of a prism in prism diopters (PD) is determined not only by A, but also by the angular position of the prism with respect to the incoming light ray that it deflects. Hence, standard positions were developed for holding both acrylic and glass prisms when measuring ocular deviations. Glass prisms were calibrated to be held in the Prentice position. Prentice's analysis was a major step forward in the calibration of prisms,[2] and the Prentice position is "eloquent" as it allows for all the refraction to occur at just 1 surface of the prism. Acrylic prisms were calibrated with respect to the minimum deviation (MD) position, originally to improve image definition (Guyton DL, personal written communication, August 2018). However these prisms in the clinical setting have been traditionally held in the frontal plane position. More in-depth details of these standards for the clinical use of prisms have been previously addressed.[4–7]

The irony is that both the MD and Prentice positions are difficult to achieve in the clinic. The MD position is not readily obvious with respect to the frontal plane of the patient, and it involves rotation of the prism apex away (anteriorly) from the patient a certain number of degrees depending on its size. On the other hand, the Prentice position requires the examiner to hold the prism such that the apex is rotated toward (posteriorly) the patient's deviated eye with the prism's posterior face perpendicular to the visual axis of that eye. This requires the examiner to estimate and align the prism to the very deviation that he or she is trying to measure. At best, both of these positions (MD and Prentice) can only be approximated, and in some situations this might result in significant errors.

In clinical practice there is a great deal of variation in how both acrylic and glass prisms are used when measuring strabismus. In an unpublished survey of 27 practitioners who regularly examine strabismus patients, 37% used solely acrylic prisms, 7% used only glass prisms, and 56% employed *both* acrylic and glass prisms. Surprisingly, the majority did not hold prisms in the accepted standard positions. In addition to the Prentice and frontal plane positions, both acrylic and glass prisms were held in other suggested positions. These included (1) holding the prism

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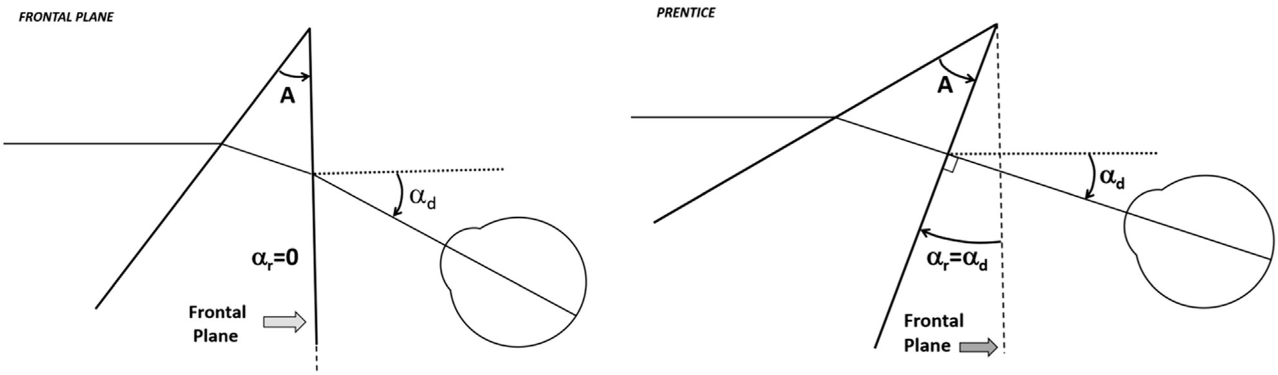

FIGURE 1. Clinical prism positions. (Left) Frontal plane position, with the posterior plane of the prism parallel to the frontal plane. (Right) Prentice position, with prism rotated in negative direction by the angle of deviation of the misaligned eye. The baseline position for the prism is shown by the dotted line(s).

with its midline plane parallel to the frontal plane and (2) with the anterior surface of the prism parallel to the frontal plane. Some in the survey (26%) admitted that as long as the prism apex pointed in the correct direction of the deviation they were not concerned about its exact rotation.

Strabismus is a relatively common ophthalmic problem for children and adults worldwide. Yet for decades there has been little published on improving the clinical accuracy of the measurement of strabismus with prisms. It is the intention of this study to critically evaluate the traditional standards for holding glass or acrylic prisms in the measurement of the clinical angle of strabismus. With this aim, this analysis will first examine mathematically in detail the effective prism power (EPP) as a function of rotational angle. Optical measurements for acrylic and glass prisms were also performed to validate the theoretical calculations. In light of the results, updated recommendations for the use of clinical prisms are made.

METHODS

ALL DATA IN THIS STUDY WERE OBTAINED BY COMPUTATIONAL analysis and optical bench measurements. No human subjects were involved.

The optics of a prism of apical angle (A) and index of refraction (n) were first analyzed with geometric optics. The index of refraction, n, was taken as 1.49 for acrylic prisms, and for glass prisms as 1.52. The baseline position was defined as the commonly understood frontal plane position with the posterior surface (toward the patient) parallel to the frontal plane of the patient. At this position the angle of rotation (α_r) is defined as zero, and the rotations of the prism were either in the positive (counterclockwise) or negative (clockwise) directions. The Prentice and frontal plane clinical prism positions are shown in Figure 1.

To calculate the effective power of a prism, in PD, the angle of deviation (α_d) for a light ray refracted by the prism must first be determined. This can be obtained for a prism rotated by any angle α_r using Snell's law at each prism-air interface. Positive or negative rotations of the prism were with respect to the baseline position of the prism and are independent of the type of strabismus (horizontal or vertical). The details of the optics of this problem and the derivations are provided in the Supplemental Appendix and Supplemental Figures 1-4 (Supplemental Material available at AJO.com).

The final formula determined for the effective prism power in PD as a function of rotational angle is as follows:

$$\text{EPP} = 100 \tan [\arcsin (n \sin (A - \arcsin ((1/n) \sin (A - \alpha_r)))) - \alpha_r]$$

Using this formula, the EPP can− be determined for each of the above desired clinical prism positions and also graphed as a function of α_r. It was also employed to do calculations for glass prisms deviated from the Prentice position by ±5 degrees and ±10 degrees.

Optical measurements of both acrylic (Gulden Ophthalmics, Elkins Park, Pennsylvania, USA) and glass (Bausch and Lomb, Rochester, New York, USA) prisms were obtained using an optical bench setup employing a helium neon laser as the light source. Indices of refraction corrected for the wavelength (632.8 nm) of the helium neon laser were considered. Measurements of the EPP were obtained for both acrylic and glass prisms in each of the above-mentioned clinical prism positions, as well as for glass prisms deviated from the Prentice position by ±5 degrees and ±10 degrees. Details of the optical setup, measurements, and calculations are presented in the Supplemental Appendix and Supplemental Figures 1-4.

RESULTS

FIGURES 2 AND 3 SHOW REPRESENTATIVE GRAPHS OF effective prism power as a function of rotational angle

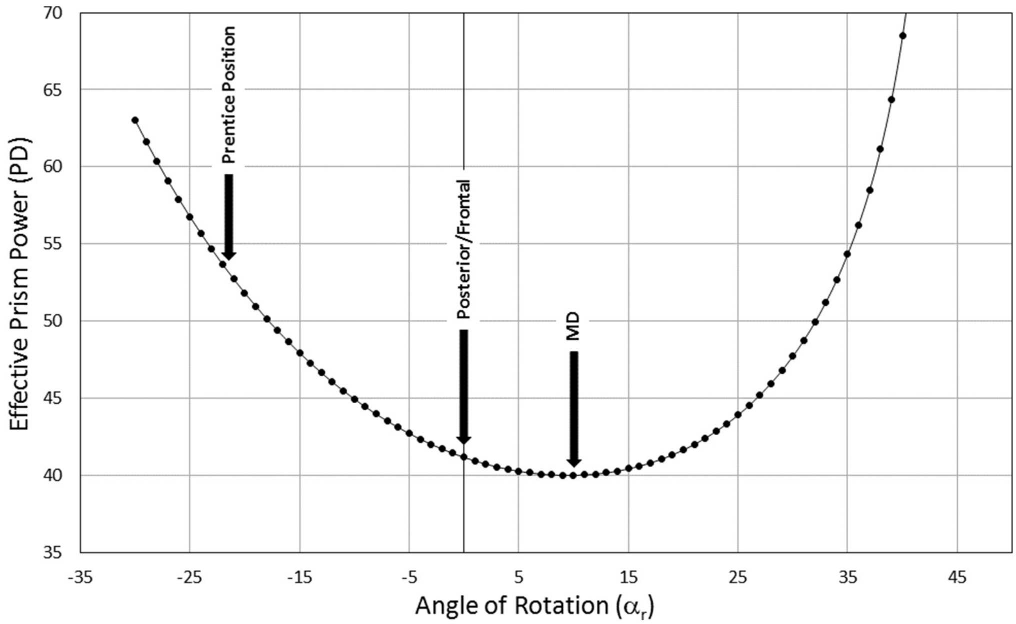

FIGURE 2. Graphing effective prism power for a 40 prism diopter (PD) acrylic prism. Effective prism power is plotted as a function of rotational angle for a 40 PD acrylic prism. The discussed prism positions are shown by vertical arrows. The minimum deviation position is also marked.

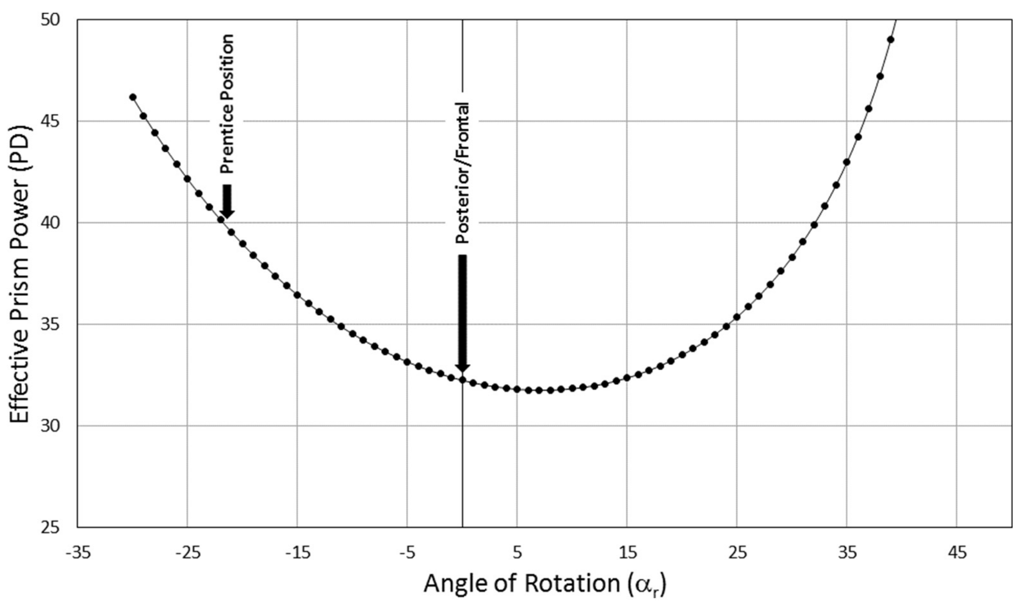

FIGURE 3. Graphing effective prism power for a 40 prism diopter (PD) glass prism. Effective prism power is plotted as a function of rotational angle for a 40 PD glass prism. The discussed prism positions are shown by vertical arrows. The minimum deviation position is not marked.

for both a 40 PD acrylic and 40 PD glass prism, respectively. The prism positions are then indicated by arrows over each graph. In addition, the MD position is shown for the acrylic prisms. Plotting the effective prism power as a function of rotational angle produced curves demonstrating that the frontal plane position lies along the flatter portions of the curves, and the Prentice position lies along a steeper portion of the curves. Additional

TABLE 1. Results of Calculations for Acrylic Prisms

Apical Angle of Prism (Degrees)	α_r at the MD Position (Degrees)	EPP MD Position (Standard)	EPP Prentice Position	EPP Frontal Plane Position
5.83	+1.48	5.00	5.02 (0.4%)	5.00 (0%)
11.58	+2.93	10.00	10.19 (1.9%)	10.02 (0.2%)
17.17	+4.32	15.00	15.66 (4.4%)	15.08 (0.5%)
22.52	+5.61	20.00	21.57 (7.9%)	20.17 (0.9%)
27.60	+6.78	25.00	28.12 (12.5%)	25.33 (1.3%)
32.35	+7.83	30.00	35.45 (18.2%)	30.54 (1.8%)
36.77	+8.74	35.00	43.83 (25.2%)	35.83 (2.4%)
40.83	+9.52	40.00	53.47 (33.7%)	41.17 (2.9%)
44.55	+10.16	45.00	64.75 (43.9%)	46.58 (3.5%)
47.94	+10.69	50.00	78.12 (56.2%)	52.06 (4.1%)

EPP = effective prism power.
EPP for each of the prism positions are shown. Values in parentheses represent percentage error in EPP from that for the accepted standard position.

TABLE 2. Results of Calculations for Glass Prisms

Apical Angle of Prism (Degrees)	α_r at the Prentice Position (Degrees)	EPP Prentice Position (Standard)	EPP Frontal Plane Position
5.47	–2.86	5.00	4.98 (0.4%)
10.73	–5.71	10.00	9.84 (1.6%)
15.61	–8.53	15.00	14.49 (3.4%)
19.98	–11.31	20.00	18.82 (5.9%)
23.80	–14.04	25.00	22.78 (8.8%)
27.07	–16.7	30.00	26.35 (12.2%)
29.83	–19.29	35.00	29.50 (15.7%)
32.12	–21.8	40.00	32.24 (19.4%)
34.01	–24.23	45.00	34.59 (23.1%)
35.56	–26.57	50.00	36.59 (26.8%)

EPP = effective prism power.
EPP for each of the prism positions are shown. Values in parentheses represent percentage error in EPP from that for the accepted standard position.

graphs for prisms ranging from 5 to 50 PD are also available in Supplemental Figures 1-4.

Tables 1 and 2 display the numerical results of these calculations, including the EPP for the prism positions for a series of prism sizes. Shown also are the apical angles (A) that correspond to the MD and Prentice positions for acrylic and glass prisms, respectively. The calculated Prentice angle and the MD angle are tabulated as well. Shown with each EPP is the percentage error with respect to the standard power for each prism in the accepted calibrated position.

For acrylic prisms (Table 1) the positive angle of rotation (α_r) needed for the MD position (and thus the difference between the MD and frontal plane position) steadily increases with increasing prism apical angle A. However, the percentage error in the effective prism power for the frontal plane position remains small (<5%) for prisms corresponding to powers all the way to 50 PD. Yet, for the Prentice position the error in the effective prism power rapidly increases to greater levels (>10%) by 25 PD prisms.

For glass prisms the required rotational angle for the Prentice position is shown for each prism power (Table 2). The frontal position actually gives acceptable errors (<5%) for glass prisms calibrated up to 15 PD, but then the error increases relatively rapidly thereafter.

The Prentice position lies along a steeper portion of the glass prism EPP curve (Figure 3) and thus small variations in the prism position can produce significant errors. Table 3 shows the calculated results for these rotational variations from the Prentice position for glass prisms. For a variance of ±5 degrees, larger glass prisms of 30 PD or larger show significant errors (>5%) and for a variance of ±10 degrees significant errors can be seen for even 10 PD and larger glass prisms.

TABLE 3. Effective Prism Power for Glass Prisms as a Function of Rotational Variations From Prentice Position

Degree Variation From Prentice Position → Prism Labeled Power	Variance			
	−5	+5	−10	+10
5.00	5.08 (1.6%)	4.98 (0.4%)	5.23 (4.6%)	5.02 (0.4%)
10.00	10.27 (2.7%)	9.83 (1.7%)	10.69 (6.9%)	9.83 (1.7%)
20.00	20.97 (4.9%)	19.31 (3.5%)	22.26 (11.3%)	18.89 (5.6%)
30.00	32.05 (6.8%)	28.43 (5.2%)	34.66 (15.5%)	27.28 (9.1%)
40.00	43.47 (8.7%)	37.26 (6.9%)	47.82 (19.6%)	35.15 (12.1%)

Values in parentheses represent percentage error in effective prism power from that for the exact Prentice position.

Optical bench measurements produced comparable results as those shown for all of the theoretical calculations, as demonstrated in Supplemental Tables 1 and 2 (Supplemental Material available at AJO.com). These were within 5% in all cases. In most cases the error was less than 2%, but for larger prisms, especially held in the Prentice position, the differences were somewhat larger. These bench measurements confirmed the accuracy of all the calculations.

DISCUSSION

ACRYLIC PRISMS CURRENTLY CALIBRATED WITH RESPECT to the MD position give acceptable deviations (<5% error) when held in the frontal position up to 40 PD. When very thick prisms are used, such as > 40 PD, the errors become more significant, and in this setting it would be ideal if the prism apex could be rotated anteriorly approximately 10 degrees. The Prentice position is an unacceptable ways to hold thicker acrylic prisms greater than 15 PD based on the large amounts of error produced. This is in agreement with Thompson and Guyton's previous conclusion regarding acrylic prisms held in the Prentice position.[5]

The analysis of prisms in this study was made only for measurement of *distance* deviations in the primary gaze position and it is important to mention the differences in positioning of acrylic prisms for both eccentric gaze and near measurements of strabismus. Acrylic prisms are to be held so that the posterior face is in the frontal plane for measurements in the primary gaze. However, for near and eccentric gaze the prisms are best held such that the posterior face is perpendicular to the direction of the fixation object. This unifying technique, where the posterior face is always held perpendicular to the line of sight to the fixation object, is described in more detail by Thompson and Guyton[5] and also by Repka and associates.[7]

Glass prisms appear useful for clinical measurements of small angles less than or equal to 10 PD. However, the potential for error in *any position* for thicker prisms is significant, and it is recommended that glass prisms not be used for measurements greater than 10 PD even when held in the Prentice positions, for the reasons stated above. We propose that it is unlikely that an examiner can, with any certainty, hold a glass prism with an accuracy of ±5 degrees of the true Prentice position. The Prentice position is eloquent when looking at its geometric optics, but clinically needs to be abandoned owing to unacceptable amounts of error that can potentially occur from its use with current glass prisms. Of note, we can find no reference to this conclusion in the literature, that glass prisms have been abandoned by strabismus specialists.

It has been stated previously that unpredictability in the results of strabismus surgery may be owing, in part, to the error in the preoperative measurements of ocular deviations.[4–6] Thus it seems incumbent, with continued progress in both spectacle lens manufacturing and strabismus surgery techniques, that strabismus measurement errors should be minimized. Using acrylic prisms held in the frontal position for distance measurements is now recommended as the preferred technique. Another step toward greater accuracy could be the manufacturing of a new set of clinical acrylic prisms that are actually calibrated to the frontal plane position.

In conclusion, more care must be taken in making strabismus measurements. It is recommended that current glass prisms are of little clinical value and should not be used for any measurements exceeding 10 PD. Current acrylic prisms can still be used, but attention must be given to appropriate positioning of the prism with respect to the patient and the fixation object. Errors will be minimized using the frontal plane position for distance measurements.

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