Combining Fresnel and block prisms to measure large angles of strabismic deviation

Mari Yaida, MD, Seiko Fujii, MD, Weiying Sun, MD, Yumi Mito, MD, Takashi Furuse, MD, PhD, and Satoshi Hasebe, MD, PhD

PURPOSE A method was developed to measure strabismic angles $>50^{\Delta}$ by stacking commercially available Fresnel and block prisms in the same direction ("piggyback prisms").

METHODS With a laser pointer (wavelength of 532 nm) as the light source, the deviation of the laser spot produced by the stacked prisms was measured on a tangent screen placed 100 cm away from the prisms. To the obtained data with combinations of Fresnel prisms (5^{Δ}-40^{Δ}) and block prisms (10^{Δ}-50^{Δ}), a cubic surface function was fitted by polynomial regression.

RESULTS The combined effect of stacked prisms was always greater than the arithmetic sum of the labeled values of two prisms (by up to 66^{Δ}), increasing exponentially with each prism power and reaching the maximum of 156^{Δ} for the Fresnel/block combination of $30^{\Delta}/50^{\Delta}$. We obtained contour plots to evaluate the optically induced additivity error and constructed look-up tables for quickly determining the combined effect of the prisms based on their labeled values.

CONCLUSIONS Stacking prisms is a practical method to evaluate a large strabismic angle that cannot be measured by any single prism and is especially useful in dealing with severely paralytic strabismus. (J AAPOS 2024;■:103961)

There are no commercially available ophthalmic prisms that can be used to measure strabismic angles $>50^{\Delta}$. To measure larger angles, one may consider adding two prisms in the same direction; however, plastic block prisms are calibrated while the posterior face of the prism is perpendicular to the incident light coming from the front (ie, frontal plane position).[1,2] Therefore, if two prisms are stacked together, this precondition is violated. In theory, if we keep each prism in an ideal position that satisfies this precondition, no measurement error should occur. However, it is impractical to adjust the angular position of the two prisms according to the corresponding prism power during the prism and alternating cover test or the Krimsky test. As an alternative, we may consider splitting the prism power and distributing two prisms to both eyes. This method is useful in cases of comitant strabismus, where the angle of deviation is constant regardless of gaze direction, but does not measure the angle in the primary eye position. Thus, we cannot apply this method to incomitant (paralytic) strabismus, where the strabismic angle varies with gaze direction.[1,3]

Clinically, it is not rare to see a patient with paralytic strabismus with an angle of strabismic deviation much greater than 50^{Δ}. To perform follow-up examinations or determine the amount of surgical intervention, we need to establish a method to measure extra-large angles in the primary position. It is also necessary to evaluate the effectiveness of muscle transposition surgery for correcting paralytic strabismus and to compare that among different procedures.[4,5] We developed a new method using commercially available Fresnel and block prisms and experimentally demonstrated how large angles of strabismic deviation can be accurately measured.

Materials and Methods

Experimental Apparatus

Figure 1A illustrates the experimental setup. A green laser pointer (ELP-G10 KOKUYO, wavelength of 532 nm, maximum power of 1 mW) was used as the light source. The pointer and a tangent screen were placed 102 cm apart on an optical bench. We positioned a Fresnel prism or a block prism 2 cm away from the pointer, such that its flat face or its posterior face, respectively, was perpendicular to the laser beam (Figure 1B-C). When using Fresnel and block prisms together, we attached the Fresnel prism to the posterior face of the block prism and placed the block prism in the frontal plane position (Figure 1D). The deviation of the laser spot induced by the prism(s), compared with the original laser spot location without a prism, was measured on the screen using a millimeter ruler. Press-on Fresnel prisms of 5^{Δ}, 10^{Δ},

Author Affiliations: Department of Ophthalmology 2, Kawasaki Medical School, Okayama, Japan

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Correspondence: Satoshi Hasebe, MD, PhD, Department of Ophthalmology 2, Kawasaki Medical School, 2-6-1, Nakasange, Kitaku, Okayama City, Okayama 700-8505, Japan (email: shasebe2009@yahoo.co.jp).

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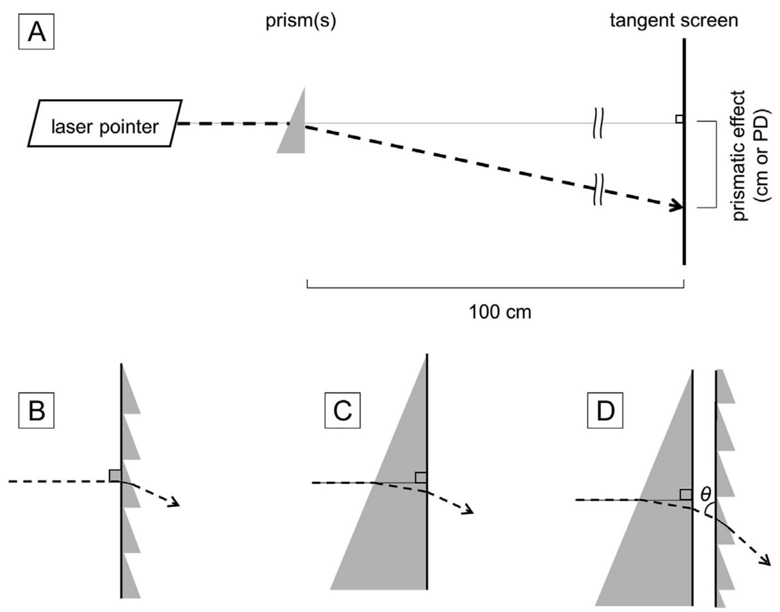

FIG 1. Schematic diagrams of the experimental setup (A) and optical paths through the Fresnel prism (B), block prism (C), and their combination (D). The dashed lines indicate the laser beam path, the bold lines (B-D) indicate the reference plane of each prism, and θ is the angle of incident light to the reference plane of the rear (Fresnel) prism.

15$^{\Delta}$, 20$^{\Delta}$, 25$^{\Delta}$, 30$^{\Delta}$, 35$^{\Delta}$, and 40$^{\Delta}$ (3M) and plastic block prisms of 10$^{\Delta}$, 20$^{\Delta}$, 30$^{\Delta}$, 35$^{\Delta}$, 40$^{\Delta}$, 45$^{\Delta}$, and 50$^{\Delta}$ (Gulden) were used. In total, we tested 71 combinations of these prisms, including the individual (uncombined) prisms.

Data Analysis

The experiment was repeated twice on different days to evaluate the repeatability of the measurements. The two measurements of the deviation were highly correlated (r = 0.999), and the mean difference (with standard deviation) between the two measurements was 0.36$^{\Delta}$ ± 1.15$^{\Delta}$ with a 95% confidence interval of 0.03$^{\Delta}$-0.68$^{\Delta}$. We determined that sufficient test-retest repeatability was obtained and thus considered the mean of the two measurements as the representative values for subsequent analysis.

Next, we fitted a cubic surface function (a multivariable polynomial equation of degree 3) to the measured deviations with the labeled values of the two prisms as the independent variables and visualized the function in contour plots using Surfer (Golden Software, LLC). This analysis smooths out the local fluctuation of the data that mainly arises from random measurement errors in this experiment and interpolates the combined effects in areas where data were not available.[6] Finally, we developed two sets of look-up tables from these values calculated by the cubic surface function to serve as a quick reference in clinical applications.

Results

In 8 of the 71 prism combinations (11%), we could not identify a laser spot on the tangent screen. This phenomenon, which may be due to total internal reflection of the rear (Fresnel) prism,[1] occurred when the combination of Fresnel/block prisms was 40$^{\Delta}$/50$^{\Delta}$, 30$^{\Delta}$/45$^{\Delta}$, 40$^{\Delta}$/45$^{\Delta}$, 35/40$^{\Delta}$, 40/40$^{\Delta}$, 35$^{\Delta}$/35$^{\Delta}$, 40$^{\Delta}$/35$^{\Delta}$, and 40$^{\Delta}$/30$^{\Delta}$. Using these combinations, with the front (block) prism held in the frontal plane position, we could hardly see a fixation target (small white bulb) at a distance of 5 m.

Figure 2A shows the contour plot of the additivity error induced by stacking the Fresnel and block prisms (the difference between the observed deviation in prism diopters and the arithmetic sum of the labeled prism values). The additivity error was always positive and increased exponentially as the labeled value of the prism(s) increased.

The combined effect of two prisms is also shown in a contour plot (Figure 2B). The fitting of the cubic surface function to the measured data points was good (root mean square error = 1.53$^{\Delta}$, R^2 = 0.93). This plot shows that with the appropriate combination, we can measure angles of strabismic deviation much greater than 50$^{\Delta}$. The combined effect also increased exponentially as the labeled value of each prism increased. Considering the area where the laser spot became invisible, the maximum combined effect was observed around 156$^{\Delta}$, using a Fresnel/block prism combination of 30$^{\Delta}$/50$^{\Delta}$. Here, the additivity error reached 66$^{\Delta}$.

Discussion

The results of this study indicate that large angles of strabismic deviations from 50$^{\Delta}$ to 156$^{\Delta}$ can be measured by stacking Fresnel and block prisms in the same direction. However, a significant additivity error occurs when the angle is evaluated by simply adding the labeled values of the two prisms, as previously indicated,[1] which can lead to an underestimation of the strabismic deviation, by up to

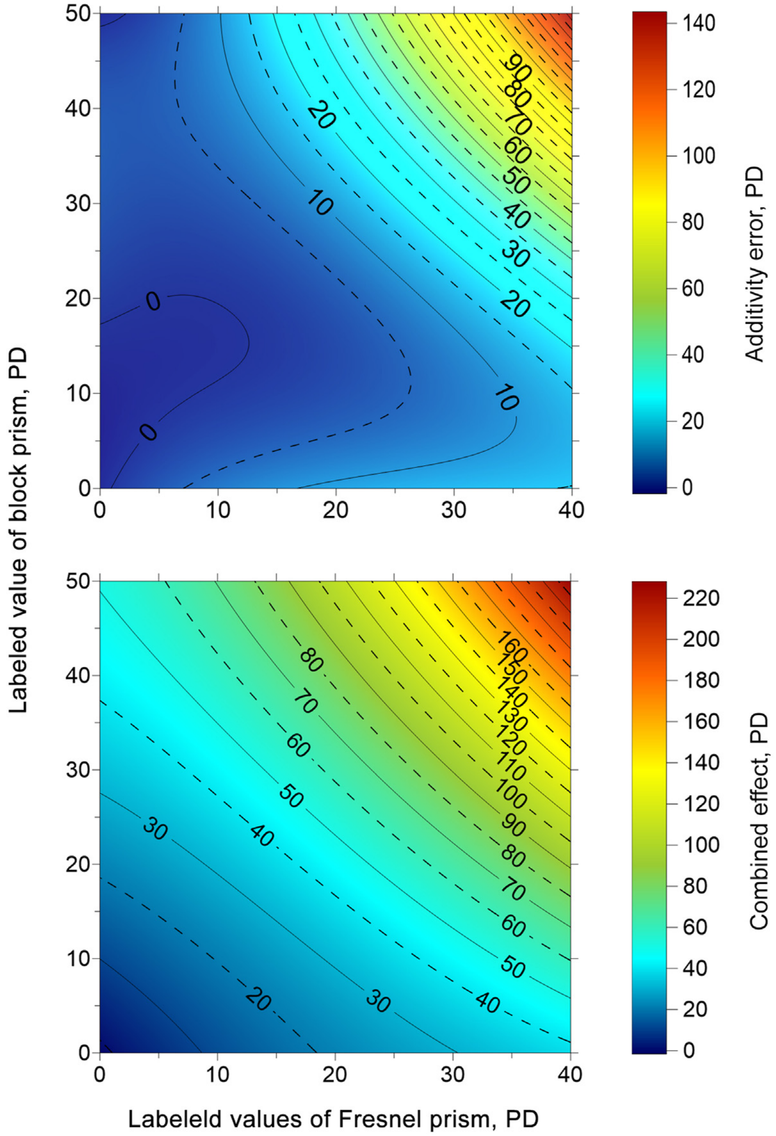

FIG 2. Additivity error (above) and combined effect (below) for the stacked prisms. the numbers along the curves represent the amount of additivity error or the combined effect.

80$^{\Delta}$. The additivity error can be explained as follows. Both the Fresnel prism (Figure 1B) and block prism (Figure 1C) are calibrated while the reference plane (posterior and flat face, respectively) of the prism is perpendicular to the incident light ray. When the two prisms are stacked in the same direction and the common reference plane is perpendicular to the incoming light from the front (Figure 1D), the angle of the incident light to the rear (Fresnel) prism (θ) is $<90°$. Consequently, the effect of the Fresnel prism becomes greater than the labeled value[1,2]) and increases with the increasing power of the front (block) prism.

When measuring an extra-large angle of strabismus, we can use the two prisms stacked together in the same direction, referring to the contour plot shown in Figure 2B. For instance, when we find neutralization of the strabismic deviation in the alternating cover test with a Fresnel/block combination of a 30$^{\Delta}$/20$^{\Delta}$, we can see that the strabismic angle is 65$^{\Delta}$ on the plot.

In practice, however, the following two methods may be more practical. In the first method (Fresnel prism fixed), a Fresnel prism of 30$^{\Delta}$ is attached to the posterior surface of the spectacle lens in advance. While the patient wears the spectacles, the examiner holds a block prism before the spectacle lens in the frontal plane position and performs the prism and alternating cover test. Here, the examiner can subsequently increase or decrease the power of the block prism and identify the prism required for neutralization. From the labeled value of the block prism, we can read the strabismic angle in Table 1. A disadvantage of this method is that relatively high-power Fresnel prisms may reduce the visibility of the fixation target, due to chromatic dispersion and diffraction.[7-9]

Table 1. Useful combinations of Fresnel and block prisms and their combined effects[a]

Fresnel prism, PD	Block prism, PD	Combined effect, PD
Fresnel prism fixed		
30	15	54
30	20	65
30	25	77
30	30	90
30	35	105
30	40	121
30	45	138
30	50	156
Block prism fixed		
1	50	52
2	50	54
3	50	56
4	50	58
5	50	59
6	50	61
7	50	64
8	50	66
10	50	71
12	50	77
15	50	86
20	50	105
25	50	128
30	50	156

[a]In the Fresnel-prism-fixed method (above), a Fresnel prism of 30^Δ is attached to the posterior surface of a spectacle lens, and a block prism is held before the lens. In the block-prism-fixed method (below), a Fresnel prism is attached to the posterior face of a block prism of 50^Δ, and the piggyback prisms are held in front of the eye. (Both methods correspond to prism arrangement D in Figure 1.)

In the second method (block prism fixed), Fresnel prisms with different powers are attached to the posterior face of a 50^Δ block prism in advance (Figure 3). The examiner holds these prisms ("piggyback prism") in the same way as for a single block prism and can perform the prism and alternating cover test. From the labeled power of each Fresnel prism, we can read the corresponding strabismic angle in Table 1. A vertical prism can be applied in front of the piggyback prism if required. If the strabismic angle exceeds a certain amount, the examiner needs to translate the prism toward the direction of the apex so that the patient can see the fixation target through this prism. Care should be taken to ensure that the patient does not see the target beyond the prism-effective field of gaze (eg, by holding the prism closer to the eye or occluding inappropriate gaze directions with the fingers).

Since the wavelength of light can alter the refractive index of a prism, the nature of the fixation target may lead to a systematic measurement error. The white light bulb that is commonly used as a fixation target emits a wide range of wavelengths and therefore the target may be seen as a band spectrum when measuring a large angle of strabismic deviation. We employed a green laser pointer in this experiment because green color has a high sensitivity for the eye and is located in the middle of the band spectrum for visible light. It may be helpful to instruct the patient in advance to gaze at the green area when a band spectrum appears. Otherwise, we can solve this problem by projecting a green laser beam onto the wall as a fixation target.

Thompson and colleagues[1] reported a method in which two plastic block prisms are stacked together to measure a large strabismic angle. We found a discrepancy in the combined effect of two prisms between their method and ours, especially when high-power prisms were stacked together. For example, the Fresnel/block combination of $30^\Delta/50^\Delta$ resulted in an overall effect of 264^Δ in their study and 156^Δ in ours. This result may be explained as follows. Considering the stacked prisms as just one prism, they used it in the frontal plane position, whereas we used it such that the common reference plane is in the frontal plane position, which is relatively closer to the minimal deviation position where the prismatic effect becomes smallest.[1,2] The difference is somewhat exaggerated by the nonlinearity of angles measured in prism diopters, but 264^Δ and 156^Δ correspond to 69° and 57°, respectively.

In conclusion, we developed a new method for measuring extra-large angles of strabismus by stacking Fresnel and block prisms in the same direction. We

FIG 3. Example of piggyback prisms. The numbers (61 and 71) on the prism base indicate the combined prism effects in prism diopters. The attached face is held in the frontal plane of the patient.

experimentally obtained contour plots and constructed look-up tables for quickly determining the combined effect of the stacked prisms based on their labeled values. This method may improve the quality of care, especially in patients with severely paralytic strabismus.

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