FRESNEL PRISMS AND THEIR EFFECTS ON VISUAL ACUITY AND BINOCULARITY*

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INTRODUCTION

OPHTHALMIC PRISMS HAVE BEEN USED IN THE TREATMENT of binocular problems for more than 100 years.[1-4] Nevertheless, until a little less than two decades ago, they have aroused only sporadic interest.[5-7] Up to that time, their use had been relegated to a secondary place by most authors interested in the management of binocular problems. Consequently, they were used little by the practicing ophthalmologist. It was not until the end of the 1950's when, having been deceived by the results of "instrumental" orthoptics, a number of strabismologists attempted to develop new methods of treatment in "free space."[8-9] This initiated a sustained revival of interest in prismotherapy, especially in Europe. Nevertheless, because of the many disadvantages inherent in conventional prisms of high powers, this new movement, as that of Guibor in the 1950's,[10] would have been as abortive as the previous ones had not a new type of prism become available.

In the mid 1960's, the 150-year-old Fresnel principle was applied to ophthalmic prisms for the first time. The first ophthalmic Fresnel prism, known as the "wafer" prism, was molded of an acrylic resin, making it much lighter and thinner than the corresponding powers of conventional prisms, thus extending the useful range of prism powers. However, this wafer prism could not be incorporated directly to a spectacle lens — rather, it had to be clipped on or taped over the patient's regular correcting glasses or used in a separate frame. Though it remains a remarkable optical and technical achievement, it was used mainly in trial testing in the United

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States. Its cosmetic appearance and the difficulty to mount it to the patient's spectacles prevented any large-scale use as a therapeutic lens.

In 1970, the Press-On™ prism, a Fresnel-principle prism molded in flexible plastic, was introduced to ophthalmologists. This thin, light membrane prism had the advantage of conforming and adhering to a smooth surface and thus could be affixed directly to a plano or basecurved correcting spectacle lens. This characteristic, together with its construction using smaller prisms with less separation, improved considerably its utility and cosmesis. Thus it appeared that at last there was an ideal therapeutic prism and, as the Press-On™ prism, it was promoted enthusiastically.[11] However, when reduced to practical application, this seemingly ideal membrane prism did not perform always in the hoped-for manner.[12] As a result, prismotherapy has lost many early advocates.

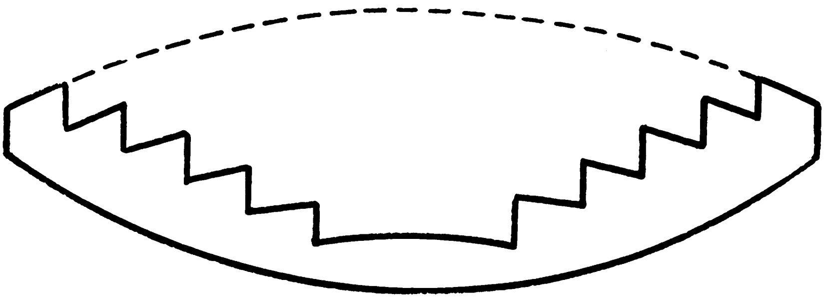
Before prismotherapy is again abandoned, the device used — the new membrane prism — must be investigated thoroughly to determine if, in fact, it may be the cause of the disappointing clinical results. That such a study is indicated is supported by the fact that a number of European authors[13-21] — leaders of the renaissance in prismotherapy — have continued to use, successfully, conventional prisms in low powers and wafer prisms in higher powers in the treatment of oculomotor anomalies.

The purpose of this thesis is to study the effects of the currently available powers of the Fresnel membrane prisms on visual acuity, fusion, and stereopsis, at near as well as at distance. The Fresnel membrane prism will be compared with the conventional prism and two other types of Fresnel prisms as well as with different lots of Fresnel membrane prisms at selected powers. A careful search of the literature revealed no such study.

Based on the results of this study, suggestions will be made as to the type or types of available prisms that appear to be the most effective for prismotherapy in strasbismus.

THE FRESNEL PRINCIPLE

It is important to review the optical principle of the Fresnel lens. It is only through a knowledge and understanding of this lens theory that the several effects of the Fresnel prism on acuity and on binocularity can be understood.



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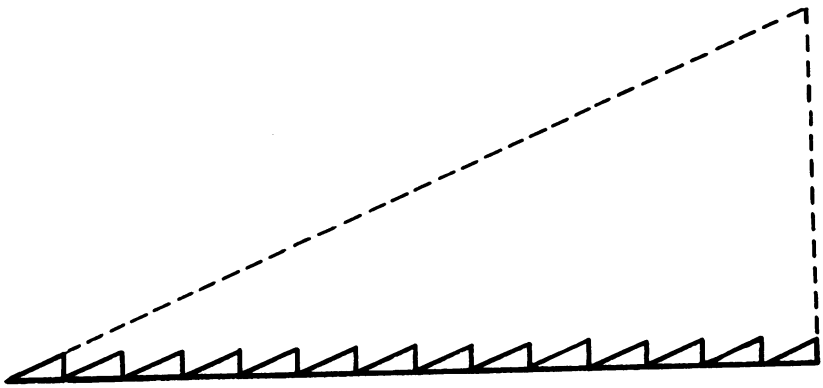

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FIGURE 1

A: Schematic cross-section of the Fresnel converging lens shows reduction in bulk (and weight). Dotted line represents anterior curvature of conventional converging lens. B: Schematic cross-section of the Fresnel prism shows much greater weight reduction and uniformly thin lens. Dotted line represents conventional prism of identical power.

In 1821, Augustin Fresnel, a French physicist, introduced a new concept on the construction of converging lenses. The massive high plus lenses made at that time, primarily for use in lighthouses, were of considerable bulk. In addition, they were difficult to construct to the power necessary to concentrate toward the horizon the light sources then available; much of the light was lost peripherally. The weight of these glass, large aperture, positive lenses required complex machinery to rotate the lens system; a lighter lens would be particularly advantageous.

Since optical systems are relatively insensitive to changes in the thickness of the system elements or their separation, Fresnel reasoned that he could overcome both problems — inadequate power and excessive weight — by employing a concentric set of prismatic rings, the face of each having the curvature of the lens element it replaced. The application of this concept resulted in a more powerful converging lens of much reduced thickness and weight (Fig. 1A). These lenses were used extensively in early automobile headlamps, for example, as well as for lighthouses, and to this day are used widely in stage lighting.

FRESNEL PRISMS

The angle of deviation, δ, that is, the light incident on a prism, is given by: $\delta = \phi_1 + \phi_2 - \alpha$ (1) where ϕ_1 is the angle of incidence on the first face of the prism, ϕ_2 is the angle between the exit ray and the normal at the second face, and α is the apex angle, that is, the angle formed by the two faces of the prism. Therefore the thickness of the prism is not a factor in determining the prismatic deviation. The Fresnel principle can be applied to flat-faced prisms with even a greater degree of accuracy than to lenses. The resulting reduction in weight is much greater in the Fresnel prism than it is in the Fresnel lens (Fig. 1B). Each small, uniformly thick, prism has the same deviating power. Equation (1) remains unaltered by the change in thickness and in weight.

THE FRESNEL WAFER PRISM

In 1965, Fletcher Woodward, an orthoptic technician, and Chester Rorie, an optician, collaborated in the design of the first ophthalmic Fresnel prism, which they called "wafer prism." This rigid, hard, acrylic, Fresnel prism was available first from 5Δ through 30Δ, and later up to and including 40Δ.*

Although the wafer prism is of uniform thickness and lighter in weight than the conventional prism, its striations are so apparent that in North America its use has been limited almost entirely to office use as a trial prism. Universal Optical Co. (Dallas, Texas), its

*Wafer prisms are available in 5, 8, 10, 12, 15, 20, 25, 30, 35 and 40 prism diopters.

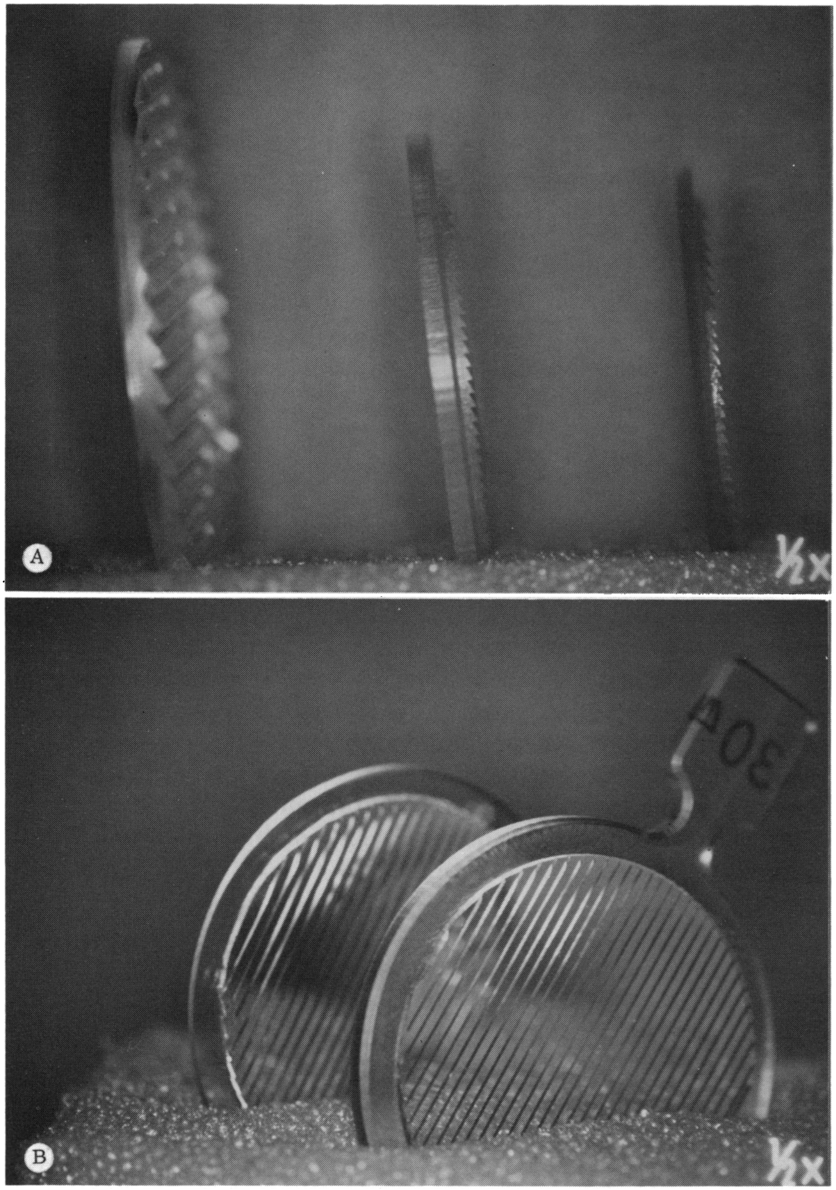


FIGURE 2

A: Left to right, Fresnel wafer prism, new Fresnel "hard" prism, and Fresnel membrane prism mounted on plano lens carrier. Note differences in thickness. B: Left rear, Fresnel membrane prism mounted on plano lens carrier. Note similarity in thickness. Right front, new Fresnel "hard" trial prism.

most recent manufacturer in this country, has stopped its production. It is still being produced in Paris by Ellisor International and is the device preferred by several European authors (Bérard, Pigassou) for prismotherapy.

THE FRESNEL MEMBRANE PRISM

In 1970, the Optical Sciences Group, Inc. (San Francisco, Cal.*) introduced into the market the new Fresnel membrane prism (Press-On™).† The flexible membrane material from which it is molded is optical-grade polyvinyl chloride (PVC). Initially the prism was made in powers ranging from 0.5Δ to 15Δ. In 1971, this range was extended to 30Δ.† Not only is this prism flexible, enabling it to conform to the base curve of the spectacle lens, but also it has an advantage over the original wafer prism in that it is thinner (Fig. 2A). Even at its maximum power, it does not exceed 1 mm in thickness.

The prism is applied while submerged in water by pressing the smooth face of the membrane to the back surface of the spectacle lens. The membrane adheres securely to the lens once the water between the two smooth surfaces has been absorbed. The flexible membrane prism must be cut smaller (about 1 mm inside the edge) than the spectacle lens to which it is to be affixed. Even a small sector of the membrane circumference overlapping the spectacle lens edge or the supporting frame, will cause a bubble of air to be trapped between the two surfaces, the seal will be broken, and the membrane will separate from the spectacle lens.

POTENTIAL ABERRATIONS OF MEMBRANE-SPECTACLE LENS COMBINATION

The spectacle lens material to which the membrane prism is to be affixed is important to the function of the prism.

Internal Reflection

The polyvinyl chloride from which the membrane prism is formed has an index of refraction[22] of 1.525 approximating that of crown glass (1.518), (AO 1.523)‡ or a CR-39 plastic (1.503) (AO 1.498)‡ spectacle lens. Such close index-matching of the lens and the

*Presently located in San Rafael, CA.

†Press-On™ prisms are available in powers of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, and 30 prism diopters.

‡Manufacturing specifications of American Optical Company

membrane prism should eliminate all problems of internal reflection which might occur if the index difference were greater than 1% or 2%.

Color Separation

Theoretically, the degree of color separation that a prism introduces into a system is related directly to the difference in the refraction between the materials, each of which has a specific color wavelength. The standard measure of this relationship is the color number (V) defined as:

V = (nF − nC) / (nD − 1)

where:

nF = index of refraction for blue-green

nC = index of refraction for red

nD = index of refraction for yellow

For spectacle glass V = 59.2 and for polyvinyl chloride V = 59.3.[23] Therefore, the addition of a flexible prismatic membrane to a crown glass or a CR-39 plastic spectacle lens should not induce chromatic effects beyond those of a conventional lens of a single material. A flint glass lens (index of refraction, 1.621; V number, 37.97) should not be used in conjunction with a PVC membrane prism since the combination would cause severe aberration problems.

Magnification

Adams and co-workers[24] compared some of the distortions inherent in the conventional prism and in the Fresnel membrane prism, when used in lenses with increasing base curves for prisms of 5Δ, 10Δ, 15Δ. These authors considered five of the distortions described by Ogle:[25] (1) horizontal magnification; (2) vertical magnification; (3) curvature of vertical lines; (4) asymetric horizontal magnification; (5) change in magnification with vertical angle. With the conventional prism, the overall magnification (horizontal and vertical) increases proportionally with increasing base curve. In contrast, the overall magnification induced by the membrane prism is minimal and relatively unaffected by a change in the base curve. With either type of prism, the other three distortions are reduced as the base curve of the lens is increased.

Because of the magnification factor, when the conventional prism is prescribed, in most instances, the total power required should be divided equally between the two eyes, otherwise monocular magnification could induce aniseikonia. The minimal magnification induced by the Fresnel membrane prism is of clinical importance in that often a high power must be prescribed only over one eye because of the reduction of visual acuity induced by the membrane prism.

VISUAL ACUITY

As stated earlier, a careful search of the literature uncovered no studies comparing visual acuity when using the conventional prism and the membrane prism of high power.

Flom and Adams[26] contend that the comparison usually made by the patient is between a Fresnel prism and no prism and not between a Fresnel prism and a conventional prism. These authors referred to only two studies. One study[27] compares the change in visual acuity induced by conventional prism and by the Fresnel membrane prism for 5Δ, 10Δ, and 15Δ powers only. The second study[28] compares visual acuity using the conventional prism, the Fresnel membrane prism, and the wafer prism only for the power of 10Δ.

FUSION AND STEREOPSIS

Surprisingly, no data is available regarding the maintenance or the disruption of fusion and stereopsis by prisms of various types and of various powers. This is paradoxical in view of the fact that the ability to maintain fusion is imperative to the concept of binocular training.

CLINICAL EXPERIMENTS ON VISUAL ACUITY AND BINOCULARITY

Clinical experiments were designed to determine how the range of powers in the various types of prisms available affect visual acuity and binocularity under controlled conditions. The subjects included in this study were selected at random. In each instance, the subject was examined to check for visual acuity (20/20, corrected or uncorrected, Snellen) and normal binocularity. The subjects selected ranged in age from 6 to 39 years, with an average age of 23 years. They were tested by an independent observer, and the findings were analyzed by a biostatistician.

EXPERIMENT I — CONVENTIONAL PRISMS COMPARED WITH FRESNEL MEMBRANE PRISMS FOR VISUAL ACUITY, FUSION, AND STEREOPSIS

Twenty-five normal subjects with visual acuity of 20/20 (uncorrected or corrected) were tested using the Fresnel membrane prism and the conventional prism with powers of 5Δ, 8Δ, 10Δ, 12Δ, 15Δ, 20Δ, 25Δ, and 30Δ. The Fresnel membrane was applied to a round plano lens with a flat base curve. The conventional prism had an identical flat or zero base curve. All lenses and prisms were of optical glass, except for the 25Δ and 30Δ conventional prisms. In the latter two instances, plastic square prisms were used because these powers were not available as round trial prisms. When the square prism was used, a lens frame, of the same inside diameter as used in the lower powers, was affixed to the back surface of each prism so that the subject was tested while looking through a frame with an aperture identical to that used for all other prism powers. In each case, the prism was placed at the same distance (12 mm) from the eye of the subject.[29] All subjects were tested under identical laboratory conditions (same room, illumination, instrumentation, and normal head position). The same experienced examiner asked each subject in a noncommitted fashion to comment on the effect of the prism.

The visual acuity through each prism was tested[30] at 20 feet using the American Optical slide, No. OS 1118, with an illumination of 56 footcandles at the screen and a room illumination of 3½ footcandles giving a contrast of over 90%. Near visual acuity was tested at 13 inches using the Rosenbaum vision screener with an illumination of 28 footcandles.

The 25 subjects were divided into two groups at random. Twelve subjects were examined with the prism applied base out, and 13 subjects with the prism applied base in. The visual acuity of all 25 subjects was tested at distance and at near, with the prism base up and with the prism base down. The visual acuity was tested also at multiple oblique axes. The distance visual acuity was tested also with the subject looking laterally 45° toward the base and 45° toward the apex of the prism. The order of these testing procedures was randomized throughout.

The fusion was tested at near with the Worth 4 dot torch, and at distance with the Worth A.O. OS 1118 slide, using paired prisms. Distance fusion also was tested with paired prisms using the American Optical Project-O-Chart Vectograph stereo test slide No. 11243-101. The stereopsis at near was tested with the Titmus test and at distance with the AO vectograph slide. Both tests use Polaroid material and are consistently reliable tests when properly performed.[31]

EXPERIMENT II — EFFECT OF WAFER PRISMS AND NEW "HARD" PRISMS ON VISUAL ACUITY, FUSION, AND STEREOPSIS

Visual acuity and binocularity were retested on eight subjects from Experiment I (selected at random) using the same powers as used in Experiment I but this time with the wafer prism. The Optical Science Group Inc. has marketed very recently a trial set of thin Fresnel prisms made of hard plastic material that will be referred to as the new Fresnel "hard" prism. The same eight subjects were retested using this new prism at the same selected powers (Fig. 2B).

EXPERIMENT III — TESTING DIFFERENT LOTS OF THE FRESNEL MEMBRANE PRISM AT SELECTED POWERS

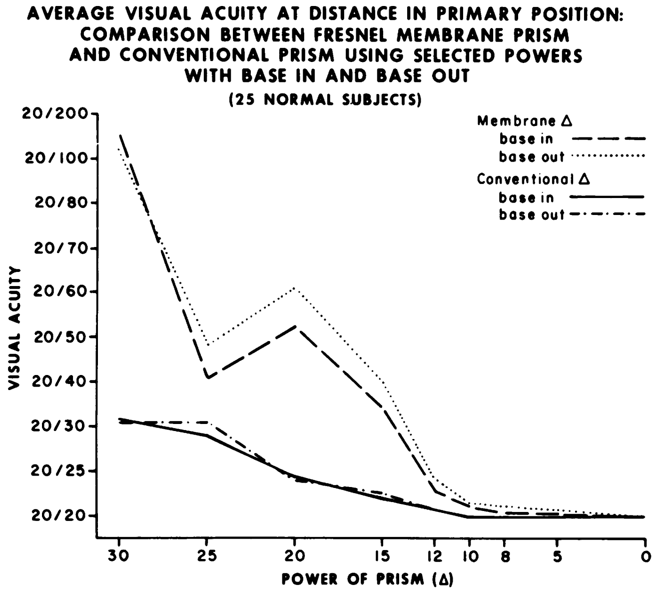
This experiment was performed because of the paradoxical finding of Experiment I that the 20Δ membrane prism reduced visual acuity more than did the 25Δ membrane prism. This departure from the expected findings pointed to a variation among different manufacturers's lots of prisms or to a manufacturing defect in the mold of the 20Δ prism. Ten new subjects (not participating in Experiments I and II) (Group B), each with 20/20 vision, were tested at distance using for each power (20Δ, 25Δ, and 30Δ) five different lots of the Fresnel membrane prism. Each of the 15 prisms was coded as to power and lot number. The code was not known to the examiner. Ten additional subjects who had participated in Experiment I (Group A) were selected at random and subjected to testing identical to that of Group B. The test conditions of Experiment III were identical to those of Experiments I and II.

RESULTS

EFFECT OF PRISMS ON VISUAL ACUITY

Fresnel Membrane Prism and Conventional Prism

In the straight-ahead gaze at distance (Fig. 3A and Table I) and in the reading position (Fig. 3B and Table II) the difference between



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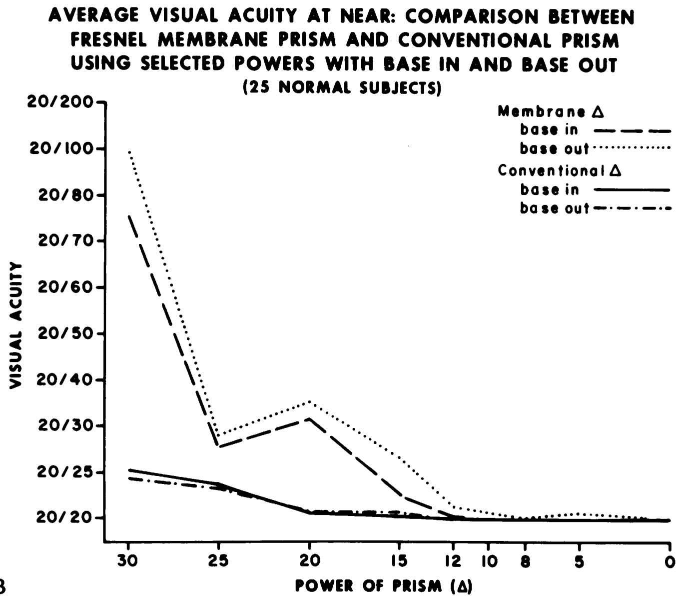

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FIGURE 3

A: Average visual acuity at distance in primary position: Comparison between Fresnel membrane prism and conventional prism using selected powers with base in and base out (25 normal subjects). B: Average visual acuity at near: Comparison between Fresnel membrane prism and conventional prism using selected powers with base in and base out (25 normal subjects).

TABLE I
AVERAGE VISUAL ACUITY AT DISTANCE IN PRIMARY POSITION: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE IN AND WITH BASE OUT

	Fresnel Membrane Prism		Conventional Prism	
	Base In	Base Out	Base In	Base Out
Number of Subjects	13	12	13	12
Power of Prism (Diopters)				
30	20/153.8	20/126.6	20/31.7	20/30.3
25	20/40.5	20/48.3	20/29.2	20/30.5
20	20/52.5	20/61.2	20/24.4	20/24.2
15	20/34.4	20/40.2	20/21.7	20/22.5
12	20/23.0	20/24.4	20/20.6	20/20.6
10	20/21.2	20/21.6	20/20	20/20
8	20/20.5	20/21.3	20/20	20/20
5	20/20.3	20/20.9	20/20	20/20
0	20/20	20/20	20/20	20/20

the visual acuity with base in and that with base out is not stastistically significant when using the membrane prism or when using the conventional prism.

The visual acuity at distance with the Fresnel membrane prism (base in or base out) is significantly poorer than that with the conventional prism ($p<.01$) when using prisms in powers from 30Δ through 12Δ (Table III).

TABLE II
AVERAGE VISUAL ACUITY AT NEAR: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE IN AND WITH BASE OUT

	Fesnel Membrane Prism		Conventional Prism	
	Base In	Base Out	Base In	Base Out
Number of Subjects	13	12	13	12
Power of Prism (Diopters)				
30	20/75.5	20/98.5	20/25.3	20/24.2
25	20/27.9	20/29.3	20/23.8	20/23.4
20	20/31.4	20/35.3	20/20.6	20/20.7
15	20/22.7	20/26.6	20/20.3	20/20.7
12	20/20.3	20/21.4	20/20	20/20
10	20/20	20/20.6	20/20	20/20
8	20/20	20/20.3	20/20	20/20
5	20/20	20/20.6	20/20	20/20
0	20/20	20/20	20/20	20/20

TABLE III
AVERAGE VISUAL ACUITY AT DISTANCE IN PRIMARY POSITION AND AT NEAR: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE IN OR BASE OUT
(25 NORMAL SUBJECTS)

	At Distance		At near	
Power of Prism (Diopters)	Fresnel Membrane Prism	Conventional Prism	Fesnel Membrane Prism	Conventional Prism
30	20/139.9	20/31.0	20/85.1	20/24.8
25	20/43.9	20/29.8	20/28.6	20/23.6
20	20/56.3	20/24.3	20/33.2	20/20.7
15	20/36.9	20/22.1	20/24.4	20/20.5
12	20/23.7	20/20.6	20/20.8	20/20
10	20/21.4	20/20	20/20.3	20/20
8	20/20.9	20/20	20/20.2	20/20
5	20/20.6	20/20	20/20.3	20/20
0	20/20	20/20	20/20	20/20

When comparing the two types of 30Δ prisms, the average difference was striking. The conventional prism lowered the visual acuity from 20/20 to 20/30− but the Fresnel membrane prism reduced the visual acuity from 20/20 to 20/100−.

At near, the difference between the visual acuity with the Fresnel membrane prism and that with the conventional prism is almost as great. At powers of 30Δ through 15Δ, visual acuity with the membrane prism was significantly poorer than that with the conventional prism (Table III). In most cases, the visual acuity using the 25Δ membrane prism was better than that using the 20Δ prism. This departure from the expected could have resulted from a single 25Δ membrane prism of better-than-average quality or from a single 20Δ membrane prism of poor quality. Experiment III was designed to test the visual acuity with different lots of Fresnel membrane prisms and to determine whether there were other important variations within the selected powers as suggested by this paradox.

The results of Experiment III clarified and confirmed the initial findings. When five different lots of Fresnel membrane prisms were tested randomly using ten new subjects (Group B) and ten subjects who had participated also in Experiment I (Group A), it was found that (Table IV): (1) for higher powers of the membrane prism — in particular, the 30Δ power — the visual acuity varied greatly among the different lots. (2) on average, the loss in visual acuity was not always proportional to the increase in prism power

TABLE IV
AVERAGE VISUAL ACUITY AT DISTANCE USING THE FRESNEL MEMBRANE PRISM OF 30Δ, 25Δ, AND 20Δ: COMPARISON OF FIVE PRISMS FROM DIFFERENT LOTS AT EACH POWER (TWO GROUPS, EACH INCLUDING 10 NORMAL SUBJECTS)

Fresnel Membrane Prisms	Power of Prism (Diopters) 30		25		20	
	Group B	Group A	Group B	Group A	Group B	Group A
Lot 1	20/36.8	20/42.2	20/33.3	20/37.8	20/34.6	20/41.1
Lot 2	20/86.2	20/125.8	20/42.4	20/48.9	20/30.6	20/33.5
Lot 3	20/44.5	20/44.7	20/48.2	20/53.8	20/34.4	20/36.6
Lot 4	20/44.2	20/45.8	20/37.6	20/43.3	20/36.0	20/38.2
Lot 5	20/43.8	20/45.8	20/30.2	20/35.7	20/38.5	20/41.7

Note: Study Group A - 10 normal subjects from Experiment 1
Study Group B - 10 normal subjects not participating in Experiment 1

as with conventional prisms. A membrane prism of lower power could induce a greater loss in visual acuity than one of higher power. In Group B, as well as in Group A, this happened in three series out of five (Table IV).

Visual acuity with high-power prisms was, on the average, significantly poorer with membrane prisms than with conventional prisms. Although within a given lot the difference may not exceed two lines, at no time can this difference be called negligible, nor can this be generalized for all lots of high-power membrane prisms. Flom and Adams have stated that "many patients note that Fresnel prisms 'reduce their vision'." They further stated that "Interestingly, acuity through Fresnel prisms compared to conventional prisms is usually reduced by less than a line on a Snellen chart, when contrast is 90% (for lower contrast objects the difference would be larger."[26] Our finding of a significantly greater visual loss is at variance with this statement but cannot be explained on the basis of lower contrast. In our test situation, the contrast is calculated to be greater than 90%.

The average visual acuity with the 30Δ prism used in Experiment I to test the ten subjects of Group A was compared with the average visual acuity attained with the 30Δ membrane prism of Lot 2. The difference between the two was not statistically significant. The poor performance with the 30Δ membrane prism in Experiment I therefore can not be considered unique.

The average visual acuity with the 25Δ membrane prism used in Experiment I was compared also with the average visual acuity of Lot 3 (the poorest average of the five), and with that of Lot 5 (the best average). Again, when the average visual acuity of each lot was

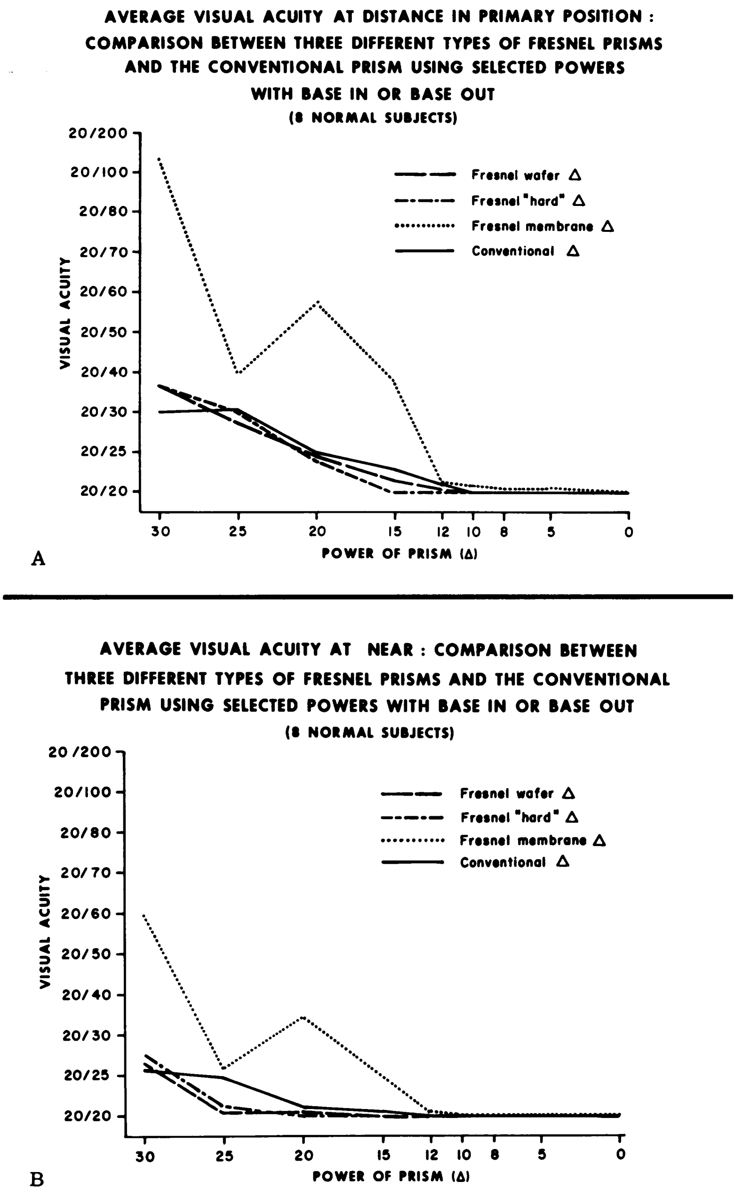

FIGURE 4

A: Average visual acuity at distance in primary position: Comparison between three different types of Fresnel prisms and the conventional prism using selected powers with base in or base out (8 normal subjects). B: Average visual acuity at near: Comparison between three different types of Fresnel prisms and the conventional prism using selected powers with base in or base out (8 normal subjects).

TABLE V
AVERAGE VISUAL ACUITY AT DISTANCE IN PRIMARY POSITION: THREE DIFFERENT TYPES OF FRESNEL PRISMS AND THE CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE IN OR BASE OUT
(8 NORMAL SUBJECTS)

Power of Prism	Fresnel Prisms			Conventional
(Diopters)	Wafer	"Hard"	Membrane	Prism
30	20/36.9	20/36.9	20/133.3	20/30.4
25	20/28.7	20/30.2	20/40.0	20/30.8
20	20/24.5	20/24.0	20/57.8	20/25.0
15	20/21.6	20/20	20/37.7	20/22.9
12	20/20.5	20/20	20/21.4	20/21.1
10	20/20	20/20	20/20.9	20/20
8	20/20	20/20	20/20.5	20/20
5	20/20	20/20	20/20.5	20/20
0	20/20	20/20	20/20	20/20

compared with that obtained in Experiment I, the difference was not significant.

When the average visual acuity with the 20Δ membrane prism used in Experiment I was compared with the average visual acuity with the 20Δ prism of Lot 5 (poorest average) the difference was significant ($p<.05$). Therefore it can be said, in general, that a 20Δ membrane prism should not reduce visual acuity as much as did the test membrane prism used in Experiment I.

Three Types of Fresnel Prisms Compared with the Conventional Prism

There is little difference in the average visual acuity through the wafer prism, the new Fresnel "hard" prism from the trial set, and

TABLE VI
AVERAGE VISUAL ACUITY AT NEAR: THREE DIFFERENT TYPES OF FRESNEL PRISMS AND THE CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE IN OR BASE OUT
(8 NORMAL SUBJECTS)

Power of Prism	Fresnel Prisms			Conventional
(Diopters)	Wafer	"Hard"	Membrane	Prism
30	20/26.7	20/27.8	20/59.9	20/25.8
25	20/20.5	20/21.1	20/25.9	20/24.8
20	20/20.5	20/20	20/34.9	20/21.1
15	20/20	20/20	20/24.9	20/20.5
12	20/20	20/20	20/20.5	20/20
10	20/20	20/20	20/20	20/20
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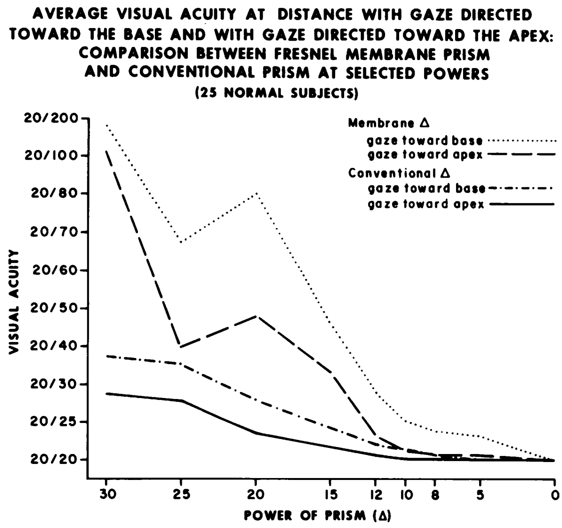
0	20/20	20/20	20/20	20/20



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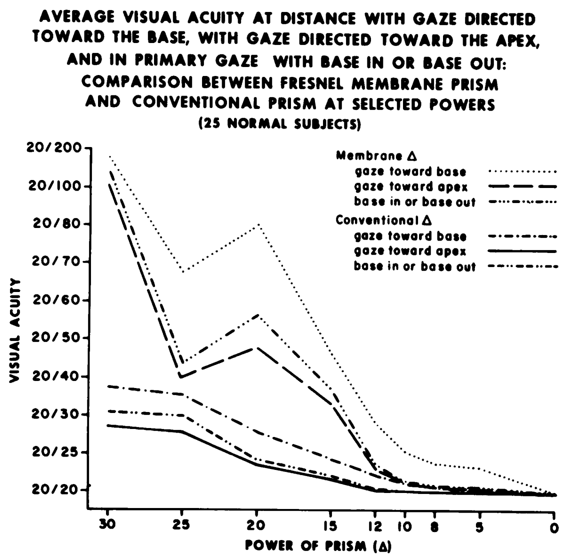

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FIGURE 5

A: Average visual acuity at distance with gaze directed toward the base and with gaze directed toward the apex: Comparison between Fresnel membrane prism and conventional prism at selected powers (25 normal subjects). B: Average visual acuity at distance with gaze directed toward the base, with gaze directed toward the apex, and in primary gaze with base in or base out: Comparison between Fresnel membrane prism and conventional prism at selected powers (25 normal subjects).

TABLE VII
AVERAGE VISUAL ACUITY AT DISTANCE WITH GAZE DIRECTED TOWARD THE BASE, WITH GAZE DIRECTED TOWARD THE APEX, AND IN PRIMARY GAZE WITH BASE IN OR BASE OUT: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM AT SELECTED POWERS
(25 NORMAL SUBJECTS)

Power of Prism	Fresnel Membrane Prism			Conventional Prism		
	Gaze Directed Toward		Base In or	Gaze Directed Toward		Base in or
(Diopters)	Base	Apex	Base Out	Base	Apex	Base Out
30	20/180.2	20/109.3	20/139.9	20/37.3	20/28.6	20/31.0
25	20/67.6	20/39.7	20/43.9	20/35.2	20/27.7	20/29.8
20	20/80.3	20/48.1	20/56.3	20/28.0	20/23.5	20/24.3
15	20/46.1	20/33.3	20/36.9	20/24.4	20/21.8	20/22.1
12	20/29.0	20/23.3	20/23.7	20/22.2	20/20.6	20/20.6
10	20/25.4	20/21.3	20/21.4	20/21.4	20/20.2	20/20
8	20/23.9	20/20.6	20/20.9	20/20.6	20/20	20/20
5	20/23.2	20/20.6	20/20.6	20/20.2	20/20	20/20
0	20/20	20/20	20/20	20/20	20/20	20/20

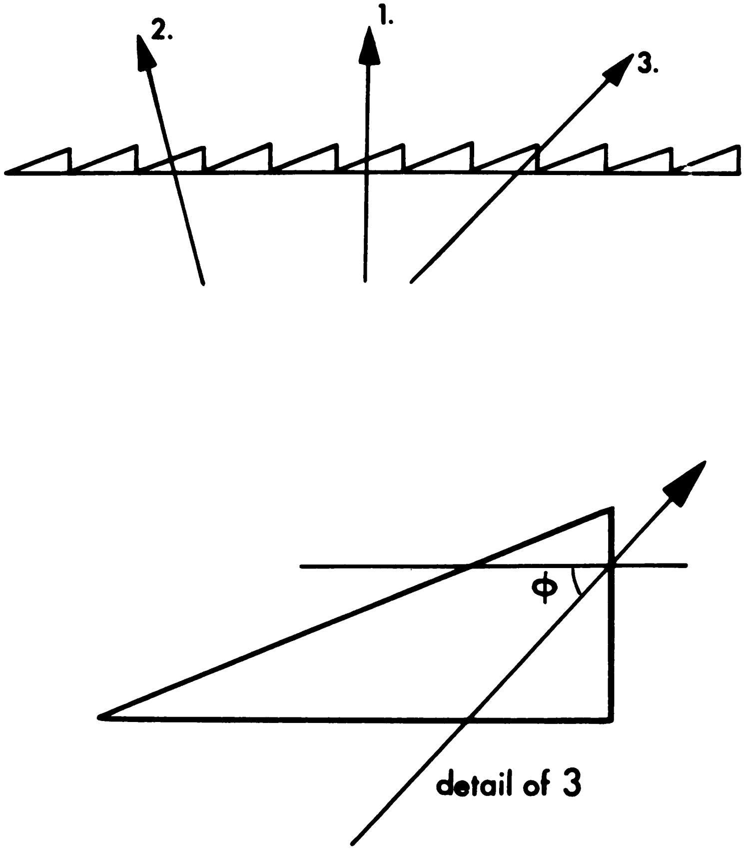
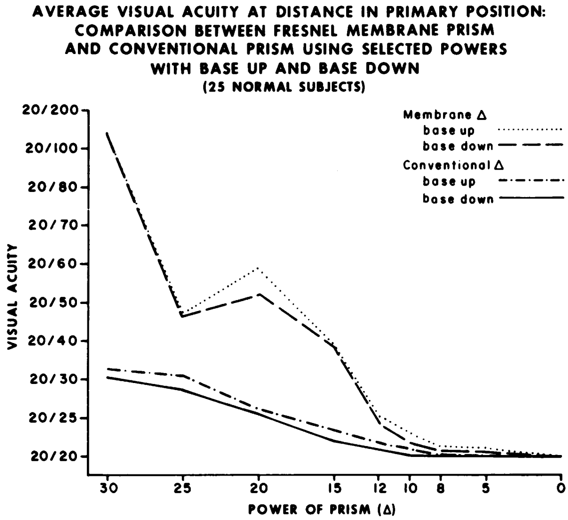


FIGURE 6
Effect of light striking prism at critical angle. Ray (3) (see detail) is deflected at the base away from eye while rays (1) and (2) pass through prism.

the conventional prism both at distance (Fig. 4A and Table V) and at near (Fig. 4B and Table VI). Although with the 30Δ wafer prism the visual acuity is slightly poorer than with the conventional prism, at prism powers lower than 30Δ, the visual acuity is better with the wafer prism and also with the new Fresnel "hard" prism. This would indicate that the poorer visual acuity with the Fresnel membrane prism is not related to a problem inherent in the Fresnel principle, as applied to prisms, but rather to problems inherent in the manufacture of the product presently available.



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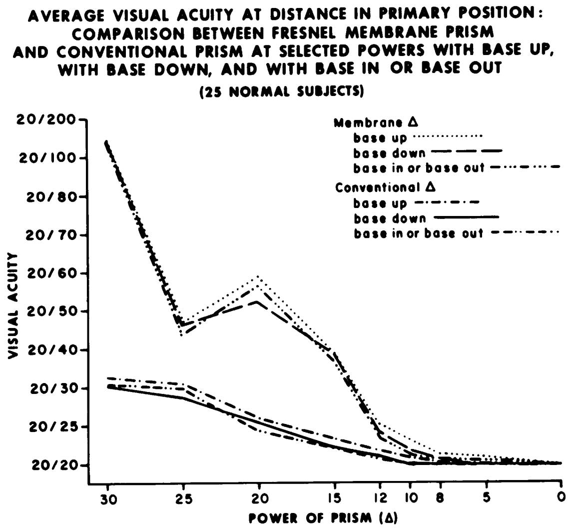
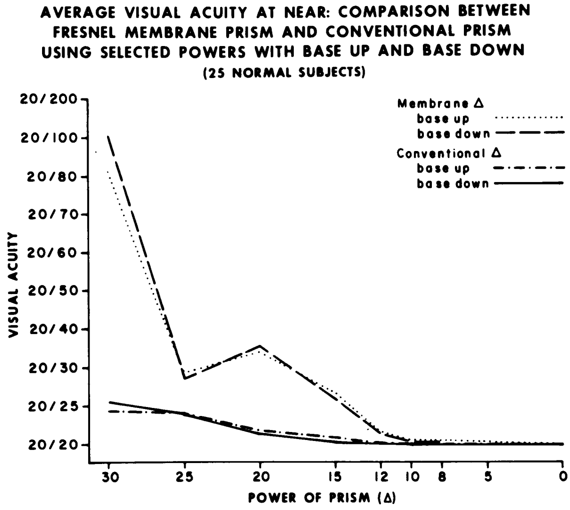


B

FIGURE 7

A: Average visual acuity at distance in primary position: Comparison between Fresnel membrane prism and conventional prism using selected powers with base up and base down (25 normal subjects). B: Average visual acuity at distance in primary position: Comparison between Fresnel membrane prism and conventional prism at selected powers with base up, with base down, and with base in or base out (25 normal subjects).



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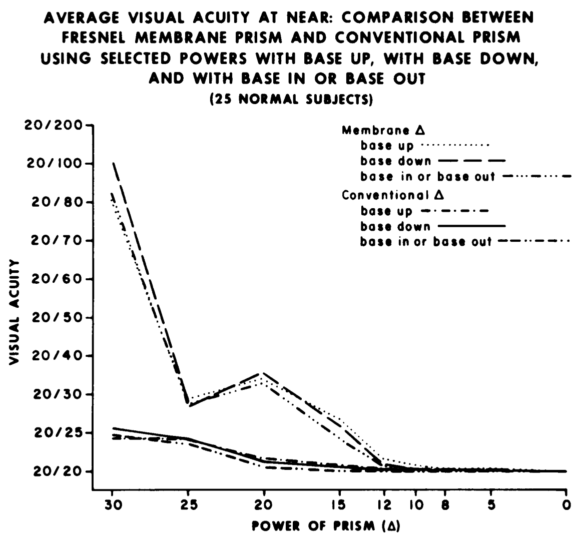


B

FIGURE 8

A: Average visual acuity at near: Comparison between Fresnel membrane prism and conventional prism using selected powers with base up and base down (25 normal subjects). B: Average visual acuity at near: Comparison between Fresnel membrane prism and conventional prism using selected powers with base up, with base down, and with base in or base out (25 normal subjects).

TABLE VIII
AVERAGE VISUAL ACUITY AT DISTANCE IN PRIMARY POSITION: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM USING SELECTED POWERS WITH BASE UP, WITH BASE DOWN, AND WITH BASE IN OR BASE OUT
(25 NORMAL SUBJECTS)

Power of Prism (Diopters)	Fresnel Membrane Prism			Conventional Prism		
	Base Up	Base Down	Base In or Base Out	Base Up	Base Down	Base In or Base Out
30	20/138.9	20/141.8	20/139.9	20/32.7	20/30.8	20/31.0
25	20/47.1	20/46.4	20/43.9	20/31.0	20/28.7	20/29.8
20	20/58.7	20/52.2	20/56.3	20/26.2	20/25.5	20/24.3
15	20/39.1	20/38.7	20/36.9	20/23.5	20/22.1	20/22.1
12	20/25.2	20/24.3	20/23.7	20/21.9	20/21.1	20/20.6
10	20/23.1	20/21.8	20/21.4	20/21.1	20/20.2	20/20
8	20/21.4	20/20.7	20/20.9	20/20.3	20/20.3	20/20
5	20/21.0	20/20.7	20/20.6	20/20.2	20/20.2	20/20
0	20/20	20/20	20/20	20/20	20/20	20/20

TABLE IX
AVERAGE VISUAL ACUITY AT NEAR: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM AT SELECTED POWERS WITH BASE UP, WITH BASE DOWN, AND WITH BASE IN OR BASE OUT
(25 NORMAL SUBJECTS)

Power of Prism (Diopters)	Fresnel Membrane Prism			Conventional Prism		
	Base Up	Base Down	Base In or Base Out	Base Up	Base Down	Base In or Base out
30	20/82.0	20/106.4	20/85.1	20/24.4	20/25.5	20/24.8
25	20/29.4	20/28.4	20/28.6	20/24.1	20/24.0	20/23.6
20	20/34.1	20/35.7	20/33.2	20/21.8	20/21.4	20/20.7
15	20/26.8	20/26.0	20/24.4	20/20.9	20/20.3	20/20.5
12	20/21.6	20/20.7	20/20.8	20/20.3	20/20.2	20/20
10	20/20.9	20/20.4	20/20.3	20/20.2	20/20	20/20
8	20/20.5	20/20.4	20/20.2	20/20.2	20/20	20/20
5	20/20.4	20/20.4	20/20.3	20/20	20/20	20/20
0	20/20	20/20	20/20	20/20	20/20	20/20

Rotation of the Prism and Visual Acuity

Rotation of the prism did not change the visual acuity at distance or at near when using either the Fresnel membrane prism or the conventional prism. This finding is of clinical importance.

In prismotherapy, it is often advantageous to prescribe an oblique prism, combining a vertical and a horizontal correction: (1) because of the high prevalence of a vertical component in strabismus in general,[32] (2) because the total power of the oblique prism is less than that required when the horizontal and vertical deviations are corrected separately,[33] and (3) when a partial occluder is desired to take advantage of the decrease in vision induced by the membrane prism. Combining the vertical and horizontal corrections in an oblique prism allows a full prismatic correction to be worn over only one eye.

Lateral Gaze and Visual Acuity

Visual acuity in lateral gazes (Fig. 5A) is compared with that in the primary position (Fig. 5B and Table VII). While there is no significant improvement in visual acuity while looking toward the apex of either the Fresnel membrane prism or the conventional prism, when looking toward the base, the visual acuity is significantly poorer ($p<.05$). This poorer visual acuity obtains for all powers of the Fresnel membrane prism and for the 30Δ through the 10Δ powers of the conventional prism.

The reduced visual acuity when looking toward the base of the prism, as compared with that when looking toward the apex, is due to the loss of light (Fig. 6). In general, the high reflectivity which occurs close to the critical angle of the prism (ray 3), reduces significantly the light available to the eye. Much more light is available for ray 1 and for ray 2 where the incidence is almost perpendicular. Thus, the patient fitted with a prism may adopt a face turn to improve his vision. The patient turns the head in the direction of the base of the prism so that his gaze is directed away from the base.

Vertical Orientation of the Prism and Visual Acuity

Vertical orientation of the prism, base up or base down, did not change significantly the visual acuity at distance (Fig. 7A and 7B, Table VIII) or at near (Fig. 8A, 8B and Table IX) when using either the Fresnel membrane prism or the conventional prism.

Again, this finding has clinical application, especially when the Fresnel membrane prism is used, as it allows the clinician to use a

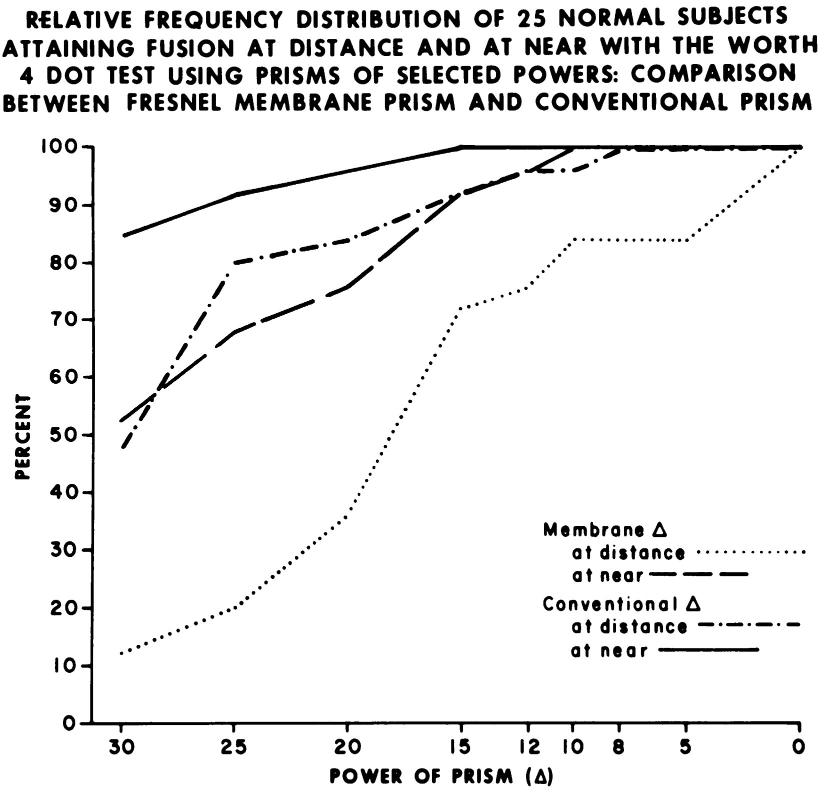


FIGURE 9

Relative frequency distribution of 25 normal subjects attaining fusion at distance and at near with the Worth 4 dot test using prisms of selected powers: Comparison between Fresnel membrane prism and conventional prism.

unilateral prism prescription over the nondominant eye or the eye with less vision without having to take into account the orientation of the prism. However, this applies only to the primary position and the reading position. If there is a choice, it would be advantageous to place the apex of the prism in the direction of the gaze most useful to the patient.

EFFECT OF PRISMS ON FUSION

The technique used to elicit fusion potential in normal test subjects must, of necessity, be different from that used on the clinical patient with a manifest deviation. The testing condition used in this study is similar to that used on the patient with nystagmus, with a

TABLE X
FREQUENCY DISTRIBUTION OF 25 NORMAL SUBJECTS ATTAINING FUSION AT DISTANCE AND AT NEAR WITH THE WORTH 4 DOT TEST USING PRISMS OF SELECTED POWERS: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM

Power of Prism (Diopters)	Fresnel Membrane Prism				Conventional Prism			
	With Fusion At Distance		With Fusion At Near		With Fusion At Distance		With Fusion At Near	
	Number	Per Center	Number	Per Cent	Number	Per Cent	Number	Per Cent
30	3	12%	13	52%	12	48%	21	84%
25	5	20	17	68	20	80	23	92
20	9	36	19	76	21	84	24	96
15	18	72	23	92	23	92	25	100
12	19	76	24	96	24	96	25	100
10	21	84	25	100	24	96	25	100
8	21	84	25	100	25	100	25	100
5	21	84	25	100	25	100	25	100
0	25	100	25	100	25	100	25	100

face turn, and with no strabismus. Paired prisms of the same power are used, one over each eye, one base in, the other base out. In the case of nystagmus, both prism bases are directed toward the face turn; in our test subjects, the base was placed, at random, to the right or to the left. Throughout all binocular testing, the head position of the subject was maintained straight.

Fresnel Membrane Prism and Conventional Prism Using the Worth 4 Dot Test.

At 20 feet, the Worth 4 dot test projects an image of 125°; at 13 inches, an image of 6°. As would be expected, the percentage of subjects with fusion is higher at near than at distance (Fig. 9 and Table X). However, the disruption of fusion differs markedly. The number of subjects exhibiting no fusion is significantly higher when using paired Fresnel membrane prisms than when using paired conventional prisms. This is the case for all powers from 12Δ to 30Δ at distance and for all powers from 20Δ to 30Δ at near. Furthermore, this disruption of binocularity by the Fresnel membrane prism cannot be attributed to the poor visual acuity through the membrane at the higher powers. The paired 30Δ membrane prisms, with an average visual acuity of 20/100 to 20/200, disrupted fusion in 88% of subjects, while the paired 25Δ membrane prisms, with an average visual acuity of 20/40 to 20/50, disrupted fusion in 80% of subjects. In contrast, paired 30Δ conventional prisms, with an average visual acuity of 20/30−, disrupted fusion in 52% of subjects, while paired 25Δ conventional prisms, with an average visual acuity of 20/30, disrupted fusion in only 20% of subjects.

With paired 30Δ Fresnel membrane prisms, most subjects stated that, at distance, with head straight, they could not see any of the four dots of the Worth test. Moreover, when looking through the base, they often experienced diplopia, whereas looking through the apex induced alternate suppression. When paired 30Δ conventional prisms were substituted, such complaints were rare.

In the testing situation, the differences found between the two types of prisms cannot be attributed to the induced lateral displacement alone. By definition, two prisms of the same power should induce, at the same distance, the same deviation, and therefore, under the same test conditions, fusion should be disrupted equally. It is more likely that the chromatic aberrations and distortions inherent in the Fresnel membrane prism are responsible for the greater disruption of fusion.

TABLE XI
RELATIONSHIP BETWEEN VISUAL ACUITY AT DISTANCE AND THE DISRUPTION OF FUSION USING THE WORTH 4 DOT TEST AT DISTANCE AND THE A.O. PROJECT-O-CHART TEST SLIDE WITH SELECTED PRISM POWERS OF THE FRESNEL MEMBRANE PRISM AND THE CONVENTIONAL PRISM
(25 NORMAL SUBJECTS)

Power of Prism (Diopters)	Fresnel Membrane Prism			Conventional Prism		
	Per Cent with No Fusion		Average Visual Acuity	Per Cent with No Fusion		Average Visual Acuity
	Worth 4 Dot	Project-O-Chart		Worth 4 Dot	Project-O-Chart	
30	88%	100%	20/140	52%	84%	20/31
25	80	80	20/44	20	56	20/30
20	64	76	20/57	16	28	20/25
15	28	52	20/37	8	12	20/22
12	24	32	20/24	4	12	20/21
10	16	16	20/22	4	8	20/20
8	16	8	20/21	0	8	20/20
5	16	8	20/21	0	8	20/20

TABLE XII
WORTH 4 DOT TEST AT DISTANCE AND AT NEAR AND VECTOGRAPH FUSION TEST AT DISTANCE: COMPARISON BETWEEN THREE DIFFERENT TYPES OF FRESNEL PRISMS AND THE CONVENTIONAL PRISM USING SELECTED POWERS. TOTAL OF 8 NORMAL SUBJECTS. (NUMBER OF SUBJECTS WITH FUSION)

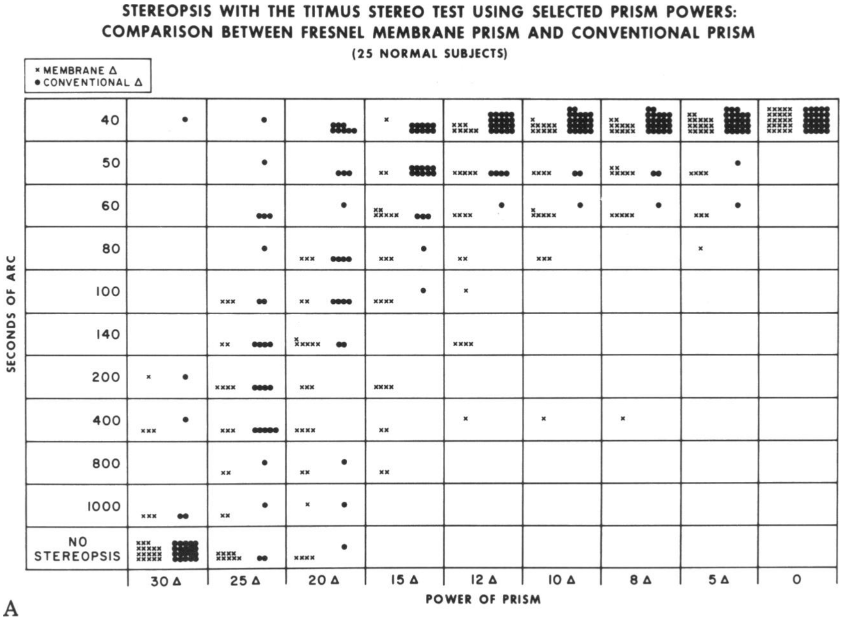
	Worth 4 Dot Test at Near							
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ
Fresnel Membrane Δ	6	7	8	8	8	8	8	8
Conventional Δ	8	8	8	8	8	8	8	8
Fresnel Wafer Δ	6	8	8	8	8	8	8	8
Fresnel "Hard" Δ	8	8	8	8	8	8	8	8
	Worth 4 Dot Test at Distance							
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ
Fresnel Membrane Δ	1	2	4	7	7	7	7	7
Conventional Δ	5	7	7	7	7	7	8	8
Fresnel Wafer Δ	1	6	8	8	8	8	8	8
Fresnel "Hard" Δ	8	8	8	8	8	8	8	8
	Vectograph Fusion at Distance							
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ
Fresnel Membrane Δ	0	1	1	3	5	5	6	6
Conventional Δ	1	5	6	6	7	7	8	8
Fresnel Wafer Δ	6	7	7	8	8	8	8	8
Fresnel "Hard" Δ	5	8	8	8	8	8	8	8

Vectograph Fusion Test

The projected vectograph fusion test is a less dissociating test than is the Worth 4 dot test and approximates more closely casual seeing. It is considered also to be more sensitive than the fusion test. Though either type of prism can disrupt fusion in normal subjects, for all prisms of 12Δ and over, the paired Fresnel membrane prisms are shown to disrupt fusion in a markedly higher percentage of subjects than the paired conventional prisms (Table XI). (Intermittent or partial fusion was not accepted as normal.) The findings of this study indicate that disruption of fusion is not related directly to reduced visual acuity (Table XI).

Three Types of Fresnel Prisms Compared with the Conventional Prism

Using the Worth 4 dot test at distance and at near and the vectograph test at distance, the paired wafer prisms — in particular, the new Fresnel "hard" prism — are seen to disturb fusion less than either paired membrane prisms or paired conventional prisms (Table XII).



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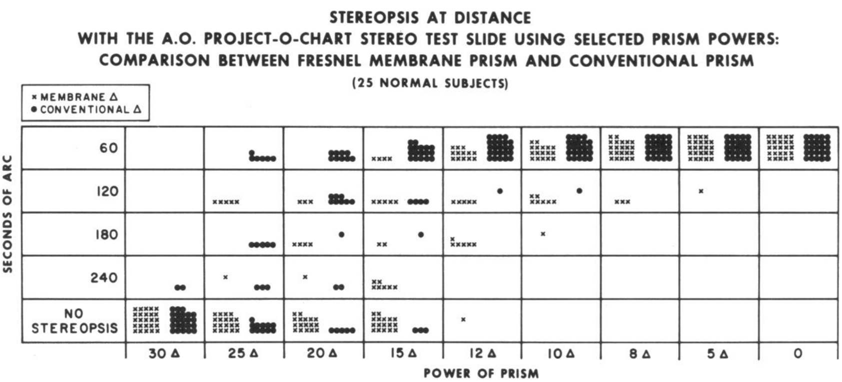

B

FIGURE 10

A: Stereopsis with the Titmus stereo test using selected prism powers: Comparison between Fresnel membrane prism and conventional prism (25 normal subjects). B: Stereopsis at distance with the A.O. Project-O-Chart stereo test slide using selected prism powers: Comparison between Fresnel membrane prism and conventional prism (25 normal subjects).

TABLE XIII
NUMBER OF SUBJECTS ATTAINING STEREOPSIS WITH THE TITMUS STEREO TEST USING SELECTED PRISM POWERS OF THE FRESNEL MEMBRANE PRISM
(25 NORMAL SUBJECTS)

Stereopsis in Seconds of Arc	Fresnel Membrane Prism (Power of prism)								
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ	0
40	0	0	0	1	8	11	12	17	25
50	0	0	0	2	5	4	7	4	0
60	0	0	0	7	4	6	5	3	0
80	0	0	3	3	2	3	0	1	0
100	0	3	2	4	1	0	0	0	0
140	0	2	6	0	4	0	0	0	0
200	1	4	3	4	0	0	0	0	0
400	3	3	4	2	1	1	1	0	0
800	0	2	2	2	0	0	0	0	0
1000	3	2	1	0	0	0	0	0	0
No Stereopsis	18	9	4	0	0	0	0	0	0

EFFECT OF PRISMS ON STEREOPSIS

Paired 30Δ membrane prisms and paired 30Δ conventional prisms, when tested at near with the Titmus stereo test, disrupt stereopsis about equally (Fig. 10A and Tables XIII and XIV). However, at powers lower than 30Δ, the conventional prism disrupts stereopsis to a lesser degree. Using paired 12Δ conventional prisms, 80% of the subjects retained full stereopsis; using paired membrane prisms, only 32%. When stereopsis is tested at distance with the vectograph slide, there is also a general shift in favor of the conventional prism (Fig. 10B and Table XV).

TABLE XIV
NUMBER OF SUBJECTS ATTAINING STEREOPSIS WITH THE TITMUS STEREO TEST USING SELECTED PRISM POWERS OF THE CONVENTIONAL PRISM
(25 NORMAL SUBJECTS)

Stereopsis in seconds of Arc	Conventional Prism (Power of prism)								
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ	0
40	1	1	8	10	20	22	22	23	25
50	0	1	3	10	4	2	2	1	0
60	0	3	1	3	1	1	1	1	0
80	0	1	4	1	0	0	0	0	0
100	0	2	4	1	0	0	0	0	0
140	0	4	2	0	0	0	0	0	0
200	1	4	0	0	0	0	0	0	0
400	1	5	0	0	0	0	0	0	0
800	0	1	1	0	0	0	0	0	0
1000	2	1	1	0	0	0	0	0	0
No Stereopsis	20	2	1	0	0	0	0	0	0

TABLE XV
NUMBER OF SUBJECTS ATTAINING STEREOPSIS AT DISTANCE WITH THE A.O. PROJECT-O-CHART STEREO TEST SLIDE USING SELECTED PRISM POWERS: FRESNEL MEMBRANE PRISM AND CONVENTIONAL PRISM
(25 NORMAL SUBJECTS)

Steropsis in Seconds of Arc	Fresnel Membrane Prism								
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ	0
60	0	0	0	4	13	17	22	24	25
120	0	5	3	5	5	7	3	1	0
180	0	0	4	2	6	1	0	0	0
240	0	1	1	7	0	0	0	0	0
No Stereopsis	25	19	17	17	1	0	0	0	0
	Conventional Prism								
	30Δ	25Δ	20Δ	15Δ	12Δ	10Δ	8Δ	5Δ	0
60	0	6	9	17	24	24	25	25	25
120	0	0	8	4	1	1	0	0	0
180	0	5	1	1	0	0	0	0	0
240	2	3	2	0	0	0	0	0	0
No Stereopsis	23	11	5	3	0	0	0	0	0

Published studies indicate that[34,35] an induced loss in visual acuity in one eye of normal subjects affects the threshold of stereopsis. In practice, this can be confirmed when a Fresnel membrane prism is used over only one eye, for example, in a paralytic strabismus with otherwise normal binocularity.

With the paired-prism method used in the present study, the visual acuity was reduced to the same extent in both eyes. Both visual acuity and stereoscopic acuity are dependent not only on the dimensions and contrast sensitivity of the retinal receptors but also on the sharpness of the image impinged upon them. Therefore it follows that reduced visual acuity should, in turn, reduce stereopsis.[36] This study confirms this relationship: subjects with markedly decreased visual acuity had poor stereopsis. However, the opposite is not true. With the 30Δ prism, there was no difference in the disruption of stereopsis (at distance as well as at near) with either prism type used (Fig. 10A and 10B, and Tables XIII and XIV), although the differences in the average visual acuity was significant (Fig. 3A and 3B). Using 25Δ paired prisms, the stereoacuity in each group improved markedly, especially with the paired conventional prisms, although improvement in visual acuity did not parallel the improvement in stereoacuity. These paradoxical results, as with fusion, may be related to prismatic aberrations.

Stereopsis With the Titmus Stereo Test Measured in Seconds of Arc: Comparison Between Three Different Types of Fresnel Prisms and the Conventional Prism Using Selected Prism Powers (8 Normal Subjects)

Fresnel Membrane Prism

Subject No.	30	25	20	15	12	10	8	5
3	x	400	200	100	60	60	60	60
4	1000	200	200	100	80	80	60	60
5	200	140	80	80	40	40	40	40
6	400	100	140	60	40	40	40	40
7	x	x	400	80	40	40	40	40
8	x	200	80	50	40	40	40	40
12	400	200	140	60	50	40	40	40
18	x	100	x	800	50	40	40	40
Diopters	30	25	20	15	12	10	8	5

Conventional Prism

Subject No.	30	25	20	15	12	10	8	5
3	400	100	50	50	40	40	40	40
4	x	800	80	60	60	60	60	60
5	200	60	40	40	40	40	40	40
6	40	40	40	40	40	40	40	40
7	x	100	40	40	40	40	40	40
8	x	60	50	40	40	40	40	40
12	x	60	40	40	40	40	40	40
18	x	140	60	40	40	40	40	40
Diopters	30	25	20	15	12	10	8	5

Fresnel Wafer Prism

Subject No.	30	25	20	15	12	10	8	5
3	60	60	50	40	40	40	40	40
4	100	80	80	80	80	80	80	60
5	200	50	50	40	40	40	40	40
6	400	80	60	50	40	40	40	40
7	200	80	80	60	50	50	40	40
8	50	40	40	40	40	40	40	40
12	60	50	40	40	40	40	40	40
18	140	60	60	50	40	40	40	40
Diopters	30	25	20	15	12	10	8	5

Fresnel "Hard" Prism

Subject No.	30	25	20	15	12	10	8	5
3	100	50	40	40	40	40	40	40
4	100	50	40	40	40	40	40	40
5	60	40	40	40	40	40	40	40
6	50	40	40	40	40	40	40	40
7	60	40	40	40	40	40	40	40
8	40	40	40	40	40	40	40	40
12	50	40	40	40	40	40	40	40
18	60	50	40	40	40	40	40	40
Diopters	30	25	20	15	12	10	8	5

Stereopsis - 40 seconds of arc   x - no stereopsis

A

Stereopsis With the A.O. Project-O-Chart Measured in Seconds of Arc: Comparison Between Three Different Types of Fresnel Prisms and the Conventional Prism Using Selected Prism Powers (8 Normal Subjects)

Fresnel Membrane Prism

Subject No.	30	25	20	15	12	10	8	5
3	x	120	120	120	60	60	60	60
4	x	x	x	x	60	60	60	60
5	x	x	x	60	60	60	60	60
6	x	120	180	120	60	60	60	60
7	x	x	x	240	180	120	60	60
8	x	x	x	240	180	180	180	180
12	x	120	120	60	60	60	60	60
18	x	x	x	x	60	60	60	60
Diopters	30	25	20	15	12	10	8	5

Conventional Prism

Subject No.	30	25	20	15	12	10	8	5
3	240	60	60	60	60	60	60	60
4	x	x	120	60	60	60	60	60
5	x	180	60	60	60	60	60	60
6	x	60	60	60	60	60	60	60
7	240	180	120	120	60	60	60	60
8	x	x	60	60	60	60	60	60
12	x	60	60	60	60	60	60	60
18	x	x	120	60	60	60	60	60
Diopters	30	25	20	15	12	10	8	5

Fresnel Wafer Prism

Subject No.	30	25	20	15	12	10	8	5
3	120	120	120	60	60	60	60	60
4	x	x	120	60	60	60	60	60
5	180	60	60	60	60	60	60	60
6	240	60	60	60	60	60	60	60
7	120	120	120	60	60	60	60	60
8	60	60	60	60	60	60	60	60
12	60	60	60	60	60	60	60	60
18	180	120	60	60	60	60	60	60
Diopters	30	25	20	15	12	10	8	5

Fresnel "Hard" Prism

Subject No.	30	25	20	15	12	10	8	5
3	60	60	60	60	60	60	60	60
4	120	60	60	60	60	60	60	60
5	120	60	60	60	60	60	60	60
6	60	60	60	60	60	60	60	60
7	60	60	60	60	60	60	60	60
8	60	60	60	60	60	60	60	60
12	120	60	60	60	60	60	60	60
18	60	60	60	60	60	60	60	60
Diopters	30	25	20	15	12	10	8	5

Stereopsis - 40 seconds of arc   x - no stereopsis

B

FIGURE 11

A: Stereopsis with the Titmus stereo test measured in seconds of arc: Comparison between three different types of Fresnel prisms and the conventional prism using selected prism powers (8 normal subjects). B: Stereopsis with the A.O. Project-O-Chart measured in seconds of arc: Comparison between three different types of Fresnel prisms and the conventional prism using selected prism powers (8 normal subjects).

FIGURE 12
"Venetian blind" effect of wafer prism.

When these tests were repeated on eight subjects using paired wafer prisms and paired Fresnel "hard" prisms, the new "hard" prisms disturbed stereopsis only minimally (the least of the four types of prisms used) both at near (Fig. 11A) and at distance (Fig. 11B). The membrane prism was the most disruptive to stereopsis.

CHROMATIC ABERRATIONS AND DISTORTIONS

All the subjects reported more chromatic aberrations and distortions with the Fresnel membrane prisms, especially at the higher powers, 15Δ and over. At 12Δ, the membrane prism showed an abrupt improvement. With the conventional prism, the improvement was more gradual.

The 30Δ membrane prism provoked the harsher criticisms as it not only induced more noticeable chromatic aberration and distortion but also blurred the vision. Optical PVC, from which the membrane prism is made, has been shown to increase chromatic dispersion and to produce a loss in contrast of objects when viewed through the prism.[26]

With all types of Fresnel prisms, reflections from the prism facets induce a second image reflected toward the base of the prism.

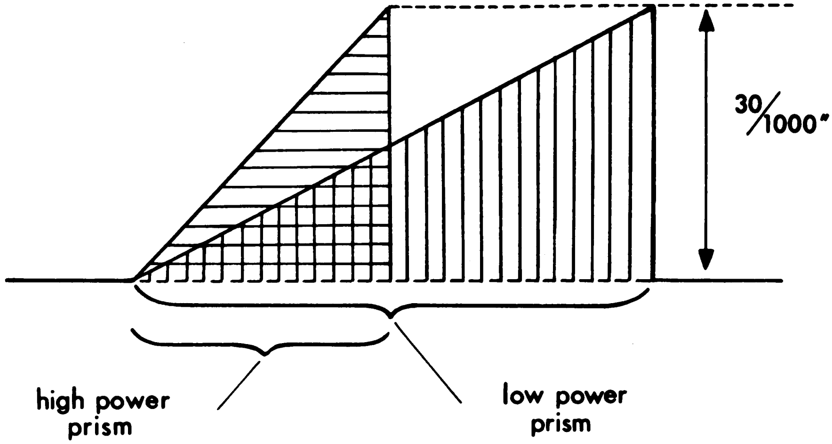

FIGURE 13
As the power of the prism increases, smaller and smaller groove widths must be used to maintain the thickness of the membrane.

These reflections are especially annoying when looking toward a brightly lit object or a light. Subjects describe the view through wafer prisms as "looking through a venetian blind" (Fig. 12). Also, with the wafer prisms, the subjects complained of kinetic movements when turning the eyes. This effect does not seem to be related to the power of the prism. No such complaints were made regarding the conventional prism, the membrane prism, or the new Fresnel "hard" prism. In the wafer prism (Fig. 2A), the width as well as the depth of each groove is greater than that in the other types of Fresnel prisms. This results in a thicker prism with more noticeable striations.

For technical (mechanical) reasons, the groove depth of a Fresnel membrane prism must not exceed 30/1,000's of an inch (.030").[37] To maintain this limit, however, smaller and smaller groove widths must be used as the power of the prism increases (Fig. 13). It would seem that with the 30Δ membrane prism a "critical point" is reached when a too-small groove width results in dispersion and precipitously reduced visual acuity.

Other factors that might have accounted for the greater chromatic aberrations found with the Fresnel membrane prism have been shown not to obtain in this study.

(1) Index-matching: The index of refraction of the carrier and that of the membrane prism were matched closely.

(2) Base curve: The carrier lens, in fact, had a flat base curve which disadvantaged the conventional prism while inducing the least aberration with the membrane prism. Most distortions associated with conventional prisms are reduced when the prism is ground with a high base curve.

(3) Air space: Since the membrane prism was not applied directly to the lens of any subject who used a spectacle correction, it could be that the space between the lens and the membrane prism would tend to increase the chromatic aberration. However, only five of the 25 subjects required optical correction: three subjects used spectacles and two used contact lenses. All five subjects were myopic. The responses of these five subjects did not differ from those of the remaining 20 subjects who did not require optical correction.

(4) Aging and surface charge of PVC: It has been well documented that the PVC material from which prism membranes are made discolor (usually yellowing) with use and aging of the plastic. In addition, the surface charge of this material attracts dirt and dust more than does glass or hard acrylic used in the manufacture of the other prisms. Any reduction in vision induced by these factors would be in addition to that found in this study, as only clean new membrane prisms were used.

The equivalence between a lens prism system of any type (wafer, membrane, conventional) and a decentered lens clearly shows that the aberrations are simply those of an object point well displaced from the optic axis for a simple lens. These aberrations are well known and well defined.[38]

THE IMPLICATIONS OF THIS STUDY IN THE TREATMENT OF STRABISMUS

Therapeutic prisms have indications for use in an expanding range of ocular motor anomalies. These anomalies may be divided into two groups.

Group I. In the adult and in the older child where well-established binocular function is suddenly disrupted or is maintained only with difficulty. The adult patient is highly motivated by the resulting diplopia to wear some type of prism to relieve the symptoms.

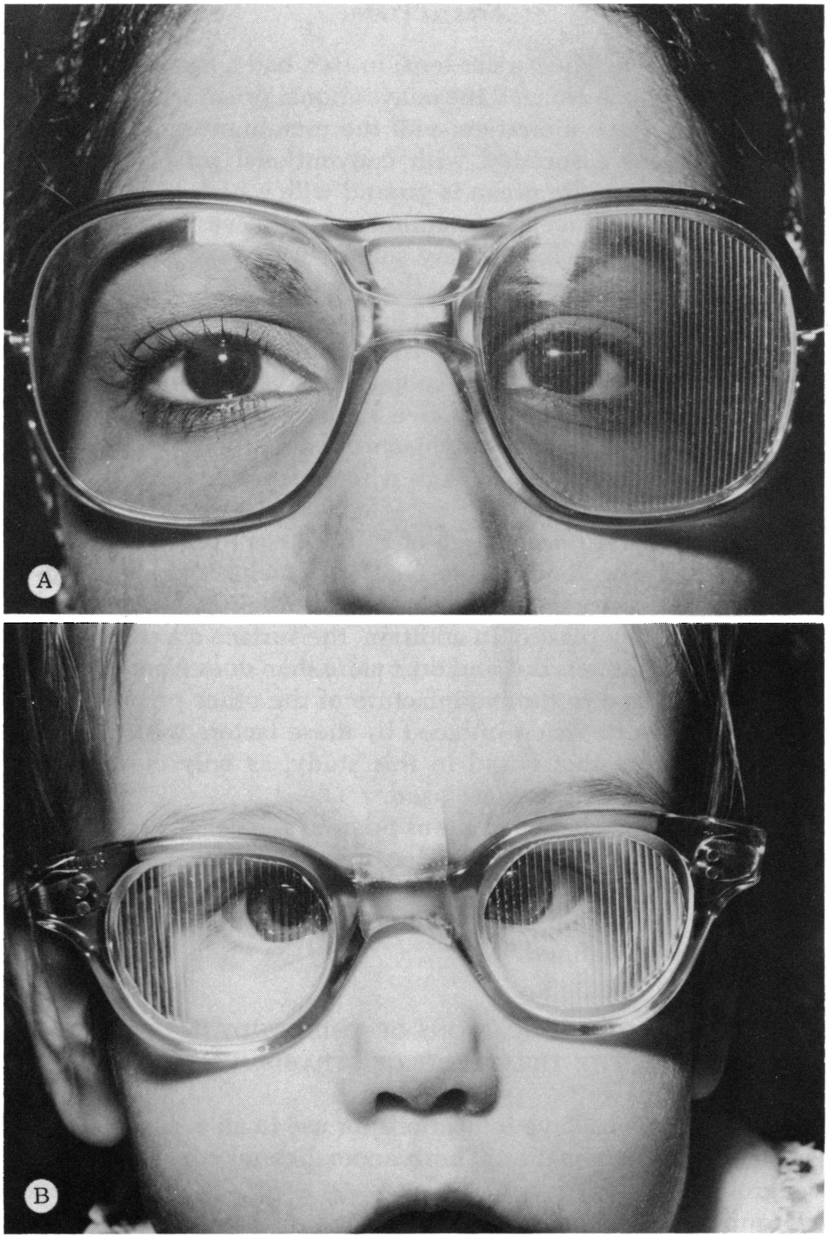

FIGURE 14

A: Case 1, (Group I). A 26-year-old woman wearing over left eye a 25Δ Fresnel prism membrane on Varilux bifocal lenses. B: One-year-old child with 25Δ base-out Fresnel membrane prisms on plano lenses.

Group II. In the child, where the binocular link either is disturbed or cannot be elicited by examination. Prisms are used, alone or in combination with other therapy, either to establish or to improve binocular function. Here the motivation is necessarily secondary. It is the parents who must take the responsibility. They will usually respond according to the prognosis given and the anticipated length of treatment proposed.

ILLUSTRATIVE CASES

GROUP I

CASE 1

Treatment Diagnosis
A 25-year-old woman with intermittent esotropia with remote near point of accommodation, diplopia, and asthenopia, presented for help but refused surgery. She had a history of two previous surgical procedures, orthoptics, phospholine iodide, bifocals since age 13, and was suspected as having a psychologic problem by the referring doctor.

Prism Therapy
A 25Δ base-out membrane prism was applied on the left lens of tinted Varilux bifocals (+0.75 add +2.75 O.U.) in June 1974 (Fig. 14A).

Result
The patient is asymptomatic wearing the prism. Her visual acuity is 20/20 O.U. With membrane prism, O.S. 20/40; at near, Jaeger 4. With the Titmus test she has 200 seconds stereopsis with the membrane prism and 80 seconds with the conventional prism. Because of cosmesis, she prefers the single membrane prism to a pair of conventional prisms despite the poorer acuity in the left eye and reduced stereopsis.

CASE 2

Treatment Diagnosis
A 60-year-old man presented with diplopia since 1974. An ultrasonogram helped confirm the diagnosis of thyroid myopathy, though he had been euthyroid since 1947. He showed incomitant esotropia with restricted abduction O.D. and a visual acuity of 20/20 O.U. He refused surgery. The prism trial test showed that the diplopia was corrected at near with 12Δ base-out prism and at distance with 25Δ base-out prism.

Prism Therapy
A 25Δ Fresnel membrane prism was applied to his right distance lens and a 6Δ conventional prism incorporated in each near vision lens. He was

asymptomatic at near. He had no diplopia at distance but his acuity was reduced to 20/50 O.D. He was annoyed by distortion and could not drive at night, with or without glasses. Incorporated conventional prisms were given; 12Δ over each eye.

Result

With bilateral conventional prisms he sees 20/20 O.U. with minimal distortion and drives comfortably. This patient prefers acuity and lack of distortion to cosmesis.

Discussion

These cases illustrate well the situation which often confronts the ophthalmologist — an adult patient with acquired strabismus and diplopia. The patient will prefer almost always to wear a prism rather than a patch to relieve the symptoms. If the strabismus is recent and variable, the Fresnel membrane prism has the advantage in that frequent, expensive changes of incorporated prism lenses are avoided. The prism trial test usually reveals that the patient will accept a Fresnel membrane only over one eye, whereas he will accept readily the divided power over both eyes in conventional prisms. Conventional prisms up to 15Δ can be incorporated in each lens.

With regard to Group II patients, controversy exists especially regarding the patient with an early onset of strabismus of deep sensory anomalies. For the patient with later onset — therefore with a better prognosis — many ophthalmologists believe that prismotherapy will not change the surgical indication.

After the preliminary findings of this study were known, the author decided to visit two European prismotherapy centers to see and to examine, at first hand, the allegedly cured patients. Both Dr. Bérard (Marseille) and Dr. Pigassou (Toulouse) showed excellent cooperation. A number of patients were examined. There was convincing proof that stereopsis and binocular function indeed were being achieved, sometimes with prisms alone, often in conjunction with surgery. This visit stimulated the author to pursue further the evaluation of different types of Fresnel prisms. This decision resulted in Experiment II. Bérard, as well as Pigassou, had tried the membrane prism and had rejected it in favor of the wafer prism because of its better tolerance and easier maintenance.

GROUP II.

CASE 1. (CASE OF DR. BERARD)

Treatment Diagnosis

A 6-year-old boy with reported onset of strabismus at age 3 was seen in consultation. Visual acuity, 20/20 O.U.; atropine refraction, +1.50 O.U. Patient had an alternating esotropia measuring 35Δ at near and at distance.

At the major amblyoscope, his objective angle was 36Δ. He showed no simultaneous perception (passed from crossed to uncrossed diplopia) with a fusion from +22Δ to +44Δ. The Titmus test was nil.

Prism Therapy

In January 1969, he was given over-correcting wafer prisms of 25Δ base-out over each eye. The power was decreased gradually over one year.

Result

January 1970: X′ 3Δ, objective angle +2Δ, fusion −6Δ to +24Δ. Titmus test, 140 seconds.

January 1976: −0.75 O.U., 20/20 O.U.; X′, objective angle −4Δ, fusion −6Δ to +12Δ. Titmus test, 40 seconds.

Discussion

The realignment of the visual axes of this patient, without surgery, and the improvement in his binocular state seem to be secondary to the prolonged use of prisms and would suggest that a prism trial is indicated in this type of patient. The age of onset, the type of deviation, and the time of follow-up are against a spontaneous reduction in the deviation.[39] The improvement in stereopsis from none at age 6 to 140 sec at age 7, to 40 sec at age 13, is also contrary to the natural history of physiologic improvement of stereopsis with age.[40] Dr. Bérard limits the indications for prismotherapy to cases similar to the above. Dr. Pigassou gives a trial even to cases with deeply rooted abnormal retinal correspondence (ARC) and with early onset of strabismus.

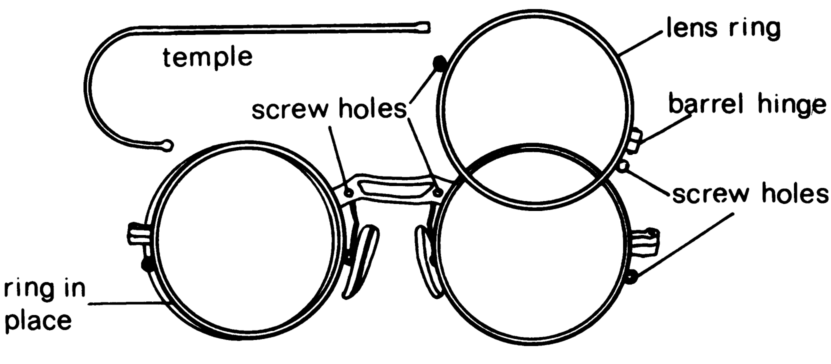

FIGURE 15

Frame designed by Bérard for mounting wafer prisms over optical correction, suitable for use with any hard Fresnel prism.

The author has verified at Dr. Pigassou's clinic that cases with ARC with afterimages had been normalized after prolonged use of prisms. Some of these achieved 50 seconds stereopsis.

It must be noted that Dr. Bérard, as well as Dr. Pigassou, make use of high power prisms on both eyes for a prolonged period. They both use wafer prisms. Dr. Bérard has developed an adjustable frame especially suited for use with hard Fresnel prisms (Fig. 15).

A one-year-old child wearing 25Δ base-out membrane prisms on plano lenses is illustrated in Figure 14B. The objections to the use of prisms in congenital esotropia are similar to the objections to early surgery. On the other hand, the advocates of early surgery should use prisms when surgery alone does not achieve parallelism.[41] Considering the findings of this study, it is the opinion of this author that this child wearing a 25Δ membrane prism bilaterally is, in effect, wearing a bilateral partial occluder. Realizing the extent to which this type of prism, at this power disrupts fusion and stereopsis in the normal subject, the author would not prescribe this prism to establish binocularity — at least, not as it is currently available.

CONCLUSION

Therapeutic prisms, based on the principle of Fresnel, when compared with conventional prisms, have been shown to be superior cosmetically and more adaptable therapeutically because of the reduced weight and thickness. Functionally, however, the Press-On™ membrane prism shows deficiencies which limit its usefulness in the higher powers required for prismotherapy. For this group of patients, a "perfected wafer," similar to the "hard" prism of the Fresnel prism trial set, would be an acceptable prism for therapeutic use. It would have a cosmesis not much different from that of the membrane prism but, in contrast to the membrane, it would not reduce the visual acuity as much, nor would it disturb the binocular function as deeply. Therefore its use may justify the goal of correcting binocular vision anomalies and re-establishing binocularity. It would seem from the findings of this study that a flexible prism is not the device of choice in prismotherapy.

SUMMARY

1. The visual acuity with the Fresnel membrane prism is significantly less than that with the conventional prism of the same power for all prism powers from 12Δ through 30Δ at distance and from 15Δ through 30Δ at near.

2. The difference in the visual acuity between base up and base down, and between base in and base out, is not significantly different for either the Fresnel membrane prism or for the conventional prism.
3. For both the Fresnel membrane prism and the conventional prism, the visual acuity when looking toward the base is significantly poorer than that when looking straight ahead.
4. Using Fresnel membrane prisms of the same power from different lots, the visual acuity varied significantly. The 30Δ prism caused the widest range in visual acuity.
5. When normal subjects are fitted with the higher powers of the Fresnel membrane prism, fusion and stereopsis are disrupted to such an extent that the use of this device to restore or to improve binocular vision in cases with large-angle deviations is seriously questioned.
6. Moreover, the disruption of fusion and stereopsis is abrupt and severe and does not parallel the decrease in visual acuity. The severely reduced ability to maintain fusion may be related to the optical aberrations, which, in turn, may be due to the molding process and the polyvinyl chloride molding material.
7. Though the flexibility of the membrane prism is a definite advantage, because of its proclivity to reduce visual acuity and increase aberrations, its prescription for adults often must be limited to only one eye.
8. For the same reasons in the young child with binocular vision problems, the membrane prism presently available should be prescribed over both eyes only in powers less than 20Δ. When the membrane prism is to be used as a partial occluder (over one eye only), any power can be used.
9. The new Fresnel "hard" prism reduces visual acuity minimally and rarely disrupts binocularity, thus increasing the potential for prismotherapy to establish binocularity. This prism is currently available only for use as a trial set.

Since the cosmetic appearance of the Fresnel "hard" prism is similar to that of the Fresnel membrane prism and it is easier to maintain, it would be the prism of choice (over all other types) for bilateral prescriptions in the young patient with emmetropia. The manufacturer is urged to make these prisms available to fit a special round adjustable frame, such as that developed in Europe for use with the wafer prism.

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