Use of prisms in ophthalmology: a review
Part 1. The use of prisms in strabismus: historical background, methodologies and their outcomes

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Keywords:
prisms, strabismus, diplopia, diagnosis, treatment

The paper points to the principle of prisms: if a prism is placed in front of the strabismic eye, images of objects impinging upon the peripheral retina are projected to the central pit, which creates optimal conditions for cooperation of both eyes and facilitates binocular vision. In strabismic eyes, prisms are used for the following purposes: measuring the angle of strabismus; determining if binocular vision or suppression scotoma is present; obtaining sensorial orthophoria with prisms and developing binocular vision; compensating for diplopia and correcting forced head rotation in paralytic strabismus; determining the maximum deviation and the amount of surgery when preparing a patient for surgery; and diploptic treatment of strabismus. The review is related also to the literature of the last fifty years on the outcomes of treating strabismic patients with Fresnel prisms. In particular, the paper presents the advantages of modified Fresnel prisms developed in Ukraine and the outcomes of treating strabismic patients with these prisms.

Prismatic correction is a conservative treatment option for strabismus. We know that when a light ray falls on a prism face it always bends towards the base of the prism. If a prism is placed in front of the strabismic eye, images of objects impinging upon the peripheral retina are projected to the central pit, which creates optimal conditions for cooperation of both eyes. Reinforcement of the fusion reflex will result in the development of binocular vision under conditions of so called sensorial orthophoria obtained with prisms. Subsequently, this will contribute to a gradual decrease in strabismus angle and development of binocular vision under normal conditions of visual perception of space [1-4].

Voinov (1873) [5], Donders (1888) [6], von Graefe (1862) [7], and Javal (1896) [8] wrote on the use of prisms in the nineteenth century.

The knowledge gained from studies by Sattler (1930) [3] contributed to wider use of prisms in strabismus. He believed that the amount of fusion could be decreased by wearing prisms to a level allowing nonsurgical strabismus treatment. However, if surgery is unavoidable, wearing prisms before surgery contributes to improved prognosis for surgical outcome. In addition, Suttler believed that prisms were most appropriate in patients with small angles of deviation, good visual acuity (VA) in both eyes, normal retinal correspondence (NRC), and short duration of strabismus at the time of prescription of prisms.

Conventional glass prisms (especially those of large power) developed initially had drawbacks and limitations such as heavy weight, aberrations, and creating a cosmetic problem due to marginal thickening of glass. In addition, this was an expansive treatment option if the amount of correction had to be changed frequently.

With the introduction of Fresnel membrane prisms in 1960s, prismatic spectacles became especially common in the treatment of strabismus. As opposed to a conventional prism, the Fresnel membrane prism, an outgrowth of the lenses designed by Augustin Fresnel, an outstanding French physicist and optician, can be imagined as a series of small prisms lying adjacent to each other on a thin transparent platform. Fresnel membrane prisms have low weight, are easily used (can be pressed onto existing prescription lenses) and changed over and of up to 30 prism diopter power (ΔD), and provide a cosmetically acceptable appearance. The disadvantage is reduced vision in the deviating eye, especially in large prism power lenses. Norden and Campos found them useful for diagnostic purposes and when the patient needed a prismatic correction for reduced periods of time and particularly when the prism power had to be frequently modified [4]. In addition, compared with conventional prisms, the amount of prismatic correction that can be tolerated is substantially higher. In the literature, they are also known as press-on prisms.

In strabismic eyes, prisms are used for the following purposes:

- measuring the angle of strabismus
- determining if binocular vision or suppression scotoma is present
- obtaining sensorial orthophoria and developing binocular vision, first with prisms, and then after removal of prisms
- compensating for diplopia and correcting forced head rotation in paralytic strabismus
- determining the maximum deviation and the amount of surgery when preparing a patient for surgery, and
- diploptic treatment of strabismus.

1. Use of prisms for measuring the angle of strabismus

A. Krimsky test

The test is indicated to estimate the deviation size in infants and in patients with nystagmus or low vision. Prisms are placed in front of the eye, with the apex pointing in the direction of the deviation, and the base oriented appropriately (esotropia, base-out; exotropia, base-in; etc.). The strength of the prism placed is increased until the corneal light reflections are symmetrical; this prism strength corresponds to the angle of deviation.

B. Alternating prism cover test (APCT)

The APCT is performed with the apex pointing in the direction of the deviation. The prism power is adjusted until no movement is detected on the cover test; this prism strength corresponds to the angle of deviation.

C. Testing with the use of prisms and Maddox rod

A bright light is shown to one eye, and its linear image obtained with the help of Maddox rod is shown to the contralateral eye. If the patient does not see the line running through the light point, and the Maddox scale is unavailable, either horizontal or vertical prism is used to displace the line closer to the light. The prism strength at which the line passes straight through the spot corresponds to the value of the subjective angle of deviation.

In each of the three tests above, measurements should be performed for distance and for near, with and without spectacles, in ocular torticollis (if present) with a straight head position, and for various gaze directions [9].

Prism-based measurements are used in various types of strabismus (horizontal, vertical and combined horizontal and vertical strabismus [1, 2, 10-18]), particularly, to compare the positions of the eyes before and after oculomotor surgery [15, 16, 19, 20].

2. Use of prisms for binocular vision or suppression studies

A. The 15-dioptre (20-dioptre) prism test

The test [9, 21] is used for fast detection of peripheral motor fusion or the dominant eye in infants, patients with speech disorders and correct position of the eyes, and patients with microstrabismus. First the 15-dioptre (20-dioptre) prism base out is performed to detect the convergent motor fusion if there is monocular movement of the eye behind the prism towards the apex. Then the test is repeated with the prism base-in to demonstrate divergent motor fusion if there is monocular movement of the eye behind the prism towards the apex. If no movement of the eye is observed, there is no motor fusion.

B. Use of prisms for determining the amplitude of fusion in patients with correct eye position or microstrabismus

The positive amplitude or convergence fusional amplitude is measured using base-out prisms (normal: 35-40 PD at near and 15-20 PD at distance). The negative amplitude or divergence fusional amplitude is measured using base-in prisms (normal: 15 PD at near and 5-7 PD at distance). Vertical fusion amplitude is measured by using a vertical prism bar base down (for measurements in the direction of supravergence) and base up (for measurements in the direction of infravergence); the normal total vertical fusion amplitude is 6 PD for near and distance. Prisms or a prism bar of increased strength is held in front of one eye until fusion breaks down and diplopia appears.

C. Suppression scotoma

Horizontal suppression amplitude is measured with base-out prisms to measure suppression to convergence and with base-in prisms to measure suppression to divergence. Vertical suppression amplitude is measured with prisms base down and base up to measure the total vertical suppression. A prism bar of increased strength is held in front of one of the eyes until suppression ends in diplopia [9].

3. Use of prisms for obtaining sensorial orthophoria and developing binocular vision

Before prescribing prismatic spectacles, patients undergo visual acuity assessment, Worth four-dot test, Bagoloni test, synoptophore assessment, and Maddox scale. Patients with baseline bifoveal fusion as assessed by synoptophore are selected for prescription of prismatic spectacles. Thereafter, cycloplegia is administered for cycloplegic refractive error measurements, and optimal spherical, cylindrical or sphero-cylindrical correction is selected. Appropriate prismatic lenses are applied onto the patient's spectacle lens after the pupils became narrow again. Binocular vision as assessed by Worth four-dot test and Bagoloni test, orthophoria (or phoria of not more than 1-2 degrees) as assessed by the Maddox scale and binocular fusion as assessed by synoptophore (close to 0 degrees) should be obtained. To obtain orthophoria with prisms, it is recommended to use prisms that correct the angle of deviation precisely; this will provide binocular vision both in the primary position of straight-ahead gaze and in the widest possible field of view. The prisms are placed with the base opposite the direction of the deviation (i.e., base out for esotropia, base in for exotropia, base out and base down for esotropia with hypertropia, etc). Either the prisms should be split equally between the two eyes or a more powerful prism should be placed in front of the dominant eye (in the latter case, a powerful prism somewhat decreases vision [10, 20, 22, 23], which will contribute to ocular dominance shifting in favor of the strabismic eye. In combined horizontal and vertical strabismus, it is reasonable to use a chart of resulting combinations of vertical and horizontal prisms to clarify the prism base direction [24]. After selecting the appropriate correction with prismatic elements, a 60-minute wearing trial should be performed two or three times to determine whether this correction will be tolerable and whether there is a secondary increase in the angle of strabismus ("prism eating" phenomenon), which is a contraindication to prolonged wearing of prisms. Only after this the appropriate sphero-prismatic, cylindro-prismatic, or sphero-cylindro-prismatic correction can be prescribed.

Treatment with prisms may be combined with the use of bifocals, occlusion, and/or pleoptic and orthoptic exercises [1, 2, 10, 12, 25].

In order to obtain orthotropia after removal of prisms, prism power should be gradually reduced, while monitoring the position of the eyes and whether binocular vision is maintained during prism therapy. This is the best possible course of action and outcome. However, commonly, a reduction in prism power or removal of prisms results in recurrence of strabismus, and surgical treatment is required. At the same time, wearing prisms before surgery has been found effective for developing binocular vision, which was beneficial for surgical outcomes. It is advisable to maintain sensorial orthophoria with prisms for 3 to 12 months before surgery [13, 14]. Most authors recommend continuing to wear prisms after surgery, if there is a residual angle of deviation. The amount of prism power should be gradually reduced until prisms can be completely discontinued.

4. Use of prisms for compensating for diplopia and correcting forced head rotation in paralytic strabismus

Prisms are selected in a way similar to those of paragraph 3. Not only readings at the devices, but also patient reports (whether the patient has no diplopia and can hold the head straight) must be monitored.

Base out prisms are used in the treatment of cranial nerve (CN) VI palsy (either unilateral or bilateral), esotropia, limited abduction and diplopia. Vertical prisms are prescribed to correct for hypertropia and remove vertical diplopia in patients with CN IV palsy. A compensatory rotation of the head, shoulders and lower extremities is common in these cases. The use of vertical prisms in combination with orthoptic treatment will improve the conditions for balancing the body position [17]. In patients with oculomotor nerve (CN III) palsy, prism treatment is often not possible, because it leads to recurrent diplopia for various gaze directions; prisms, however, may be prescribed for residual post-surgical deviations in these patients.

Double prisms allow individuals with supranuclear palsy to change gaze directions. Base in prisms are prescribed to correct exodeviation and reduce diplopia in primary gaze in patients with internuclear ophthalmoplegia [9].

Numerous reports of the efficacy of prismatic correction have been published since the nineteen sixties. These reports are relevant to theoretical basis for the use or prisms, prism calculations [26-28], importance of correctly placing prisms [29] and outcomes of prismatic correction [1, 2, 4, 10-13, 19, 20, 30-32].

In a study by Berard (1972) [13], of the 185 patients (age, 2 to 5 years) treated with permanent prism wearing but not surgery for concomitant strabismus, the complete success of treatment was achieved only in 13 patients (7%). In addition, in patients treated with a combination of prismatic therapy and surgery, the complete success rate was 57%, and the partial success rate was 26% [13].

Of the 91 patients (age, 6 to 16 years) treated for concomitant strabismus by Kashchenko (1977) [2], the complete success of treatment (restoration of ortotropia and binocular vision without prisms) was achieved in 34.8%, and the partial success (restoration of ortotropia and binocular vision with Fresnel press-on prisms) was achieved in 24.2%.

Avetisov and colleagues (1983) [1] examined the outcomes of their treatment for strabismus with prisms for 15 years. Binocular vision was obtained without prisms in 91 patients (33.6%), and was possible only in prismatic spectacles in 114 patients (42.1%) of the 271 patients with an esotropia who were prescribed prisms in combination with orthoptics.. In addition, of the 47 children with exotropia, binocular vision was obtained in 17 (36.2%). The authors concluded that prismatic correction (1) can be recommended only as an adjunct to a combination of surgery and orthoptics, and (2) contributed to success of treatment only in one-third of patients with bifoveal fusion. Given that patients with bifoveal fusion account only for 30-35% of total patients with strabismus, the total success rate will be approximately 10-15%.

In a study by Terekhova and colleagues (2008) [12], otrotropia (phoria) was obtained without surgery in 4.5% of the 266 patients with a small (≤ 10 degrees) angle of strabismus treated with Fresnel prism correction plus orthoptics.

Serdiuchenko (2018) [11] reported on her experience on the use of prismatic correction in 63 patients (age, 5 to 16 years) with a small-angle strabismus (6 to 20 prism diopters) and bifoveal fusion as assessed by synoptophore. The follow-up duration ranged from 5 to 28 months. By the end of follow-up, prismatic correction was completely withdrawn, and binocular vision without glasses was maintained in 3 patients (4.8%), and otrotropia as well as binocular vision was maintained only under conditions of prismatic correction in 42 (66.7%).

Kurochkin and colleagues (2018) [10] examined the outcomes of Fresnel prism correction as an adjunct to combination treatment for concomitant strabismus in 428 patients. By the 3 years of treatment without surgery, orthophoria was achieved in 24 patients (5.6%).

The above described method for obtaining sensorial orthophoria with prisms is most appropriate in patients with the late onset (after 2 years) and short duration of strabismus in the presence of bifoveal fusion at baseline, whereas prismatic compensation of the angle of strabismus in the presence of anomalous retinal correspondence (ARC) is of low efficacy. In the literature this is explained as follows.

Attention has been drawn to the phenomenon of a secondary increase in the angle of strabismus after obtaining a prismatic balance (“prism eating” phenomenon): within seconds to days after prismatic or surgical correction of the objective angle of strabismus, initial strabismus angle recurs under the influence of binocular perception in the free space. Some authors believe that this phenomenon is based on the anomalous retinal correspondence (ARC) [14, 33]. Kashchenko (1977) [2], however, hypothesized that an increase in the angle of strabismus is caused by reflex displacement of the eye in the direction of the deviation in an effort to eliminate prism-induced diplopia and to return the image to the area of functional scotoma. In this connection, the effect of prolonged wearing of prisms on the type of deviation (prism adaptation test) should be studied in order to determine whether it is reasonable to correct strabismus surgically and the amount of surgery.

5. Use of prisms for determining the maximum deviation when preparing a patient for surgery (prism adaptation test)

The test is used to determine the maximum deviation, most commonly, before strabismus. First, alternating prism cover test (APCT) is used to measure the angle of strabismus, the patient wears prisms for 30-45 minutes, and the angle of strabismus is measured again. If the deviation is found to be increased by more than 8 PD, the prism power is increased accordingly. The patient with a more powerful prism is supervised by the physician. If the deviation is found to be stable, the maximum deviation is recorded, and the patient should undergo surgery for the largest deviation measured [9].

Some authors studied the effect of wearing of prisms on the angle of strabismus and attempted to study the relationship between the changes they identified and postoperative results [31, 34-37]. A multicenter, prospective, and randomized study [38] was published in 1990 that reported the efficacy of prism adaptation in the surgical management of acquired esotropia. This study showed that the success rate in patients whose angle increased under the influence of prisms base-out was higher after augmented surgery than when conventional surgery was performed. However, Greenwald (1996) [39] did not confirm this finding of the multicenter study. Noorden and Campos [4] believed that there remained additional questions regarding the prism adaptation study in terms of the nosologic homogeneity of the study group and the influence of the sensorial state of patients undergoing prism adaptation. Moreover, there were no clear directions as to how much the surgical dosage needs to be augmented when prisms are ‘‘eaten up.’ That is why Noorden and Campos have not adopted the prism adaptation procedure to determine the dosage of surgery [4]. The prism adaptation test, however, has been successfully used by Rykov [19] and Shevkolenko [20].

Arruga (1971) [40] believed that wearing of prisms may be useful for the prognosis of surgery: if, after wearing the prismatic overcorrection for a long time, it is found impossible to remove or reduce this overcorrection without an increase in strabismus angle, one may assume that orthophoria will be not stable, and strabismus will recur after surgery. Preoperative prismatic correction may also indicate the prognosis for postoperative diplopia and indicate the deviation that may be surgically corrected without risk, while leaving the second image in the suppression area [26].

Another application of prisms is for treating ARC directly, which was the subject of several reports published in the nineteen seventies [32, 33, 41, 42]. Many authors have claimed that prismatic overcorrection (changing an esotropia to an exotropia) results in shifting the false macula in the required direction, which creates especially favorable conditions for spontaneous restoration of normal retinal correspondence. Von Noorden и Campos (2002) [4] noted that there were no studies that establish that preoperative prismatic therapy improves the functional results of surgery, and, likely for this reason, the prismatic-only treatment of ARC has been largely abandoned.

Clinicians prescribing prisms to patients have paid attention to some disadvantages of prisms, such as spherical aberration, oblique astigmatism, and chromatic dispersion. Fresnel prisms are made of optical polyvinyl chloride and this material increases chromatic dispersion and produces a loss of contrast. In a study by Woo and colleagues (1986) [43], the effect of chromatic dispersion on contrast sensitivity was determined. Decreases in visual acuity and contrast sensitivity threshold depend on the power of the prism, and this should be taken in account while treating strabismus patients [43].

In order to remove the shortcomings of Fresnel prisms, an extensive work on improvement of these prisms have been carried out in Ukraine in recent years. Modified Fresnel prisms were developed by Kyiv Eye Microsurgery Center in collaboration with the Institute for Information Recording of the NAS of Ukraine [44-47]. Novel prisms are made of rigid plastic that is not deformable and does not cause spherical aberration, as opposed to conventional elastic plastic Fresnel prisms that are easily deformable and wear out, can easily become dirty and do cause spherical aberration. A protective cover of microprism surface improves its tightness and makes novel prisms suitable for long-term use, cleaning with aqueous solutions, and disinfecting with appropriate agents. In addition, novel microprisms are of lower weight and thinner compared to conventional prisms. Moreover, they can be inserted along with lenses correcting for ametropia into a trial spectacle frame, as opposed to conventional prisms. A KK-42 set of 42 prismatic strabismus compensators was developed on the basis of novel microprisms to allow for measuring small and moderate angles of strabismus with an accuracy of ±1 and ±2 prism diopters, respectively [20, 47, 48]. In addition, prism bars have been produced which provide easier strabismus angle measurement compared to individual prisms inserted into a spectacle frame and a technology has been developed for welding prisms to spherical and spherocylindrical lenses to allow for correcting both for refractive error and for strabismus angle [47]. Moreover, a methodology has been proposed for using the above set to determine appropriate surgical dosage for small-angle strabismus [19, 20]. Reports have been published on the outcomes of treatment with modified Fresnel prisms for strabismus.

A study by Shevkolenko (2011) [20] found that prism correction for small-angle strabismus with the help of a KK-42 set allowed for simultaneous vision as assessed by Worth four-dot test in 72.4% of patients. In addition, it allowed for binocular vision as assessed by Bagolini test in 14.8% of patients with partial accommodative esotropia and 34.4% of patients with non-accommodative esotropia. That author developed a methodology for small-angle strabismus surgery planning and dosing on the basis of determination of strabismus angle by alternating test with the help of a KK-42 set and prism adaptation trial and taking in account the state of convergence and topographic-anatomical patterns of operated muscles. The methodology allowed obtaining orthotropia in 90.5% of operated patients [20].

It has been reported also that modified and well as conventional Fresnel prisms somewhat decrease visual acuity and contrast sensitivity [20, 22]. However, a positive aspect of this fact was used, and a more powerful prism was prescribed for the dominant eye for the purpose of penalization [23].

In a study by Mellina (2017) [23], 149 children with concomitant strabismus and amblyopia were divided into two groups. Group 1 (control group; 61 children) underwent conventional pleoptic and orthoptic treatment with occlusion of the dominant eye for 2 to 4 hours a day. In group 2 (main group; 88 children), the treatment consisted in wearing spectacles in which refractive error correction lenses were inserted along with modified Fresnel prisms. At 6 months, children of the main group exhibited better visual acuity and contrast sensitivity than those of the control group both for the amblyopic and for the dominant eye. In addition, 22.7% of patients of the former group 2 versus 1 patient (1.6%) of the latter group developed binocular vision. The author believed that better treatment outcomes were achieved in the main group partially due to the constant effect of prism correction, whereas controls received short courses of apparatus-based treatment [23].

It is noteworthy that, some researchers, including Reineke (1972) [49], were or are of the opinion that one should not expect much from prism treatment for strabismus. Among the patients of Reineke, there were too many those who were unable to tolerate correction with high diopter (over 15 prism diopter) prisms.

Nevertheless, prism treatment for strabismus is becoming increasingly popular in many countries, because it is the only method that allows achieving permanent bifoveal stimulation under natural conditions of vision in patients with concomitant strabismus. It can be used in patients of any age, but is particularly suited for children of the preorthoptic age (prior to age 3), the age at which the patient is unable to receive apparatus-based ortoptic treatment.

6. Use of prisms for diploptic treatment of strabismus

Today, there is no doubt that treatment of concomitant strabismus under conditions of free space is advantageous. Avetisov [50] proposed diploptics as a coherent system of exercises for strabismic patients. The main principle of diploptics is to cause the double-vision phenomenon in a patient in natural conditions, to "revive" or bring up the capability to overcome it by means of opto-motor fusion reflex and thus to restore the bifixation self-regulating mechanism that is the basis of normal binocular vision. The method of restoring the bifixation mechanism is one of the major methods of diploptic treatment (1976) [1]. And involves three phases: first, causing diplopia; second, bringing up the capability to fuse double images; and third, reinforcement of the bifixation reflex. In all types of diploptic treatment, the baseline deviation should be compensated by prisms, and prisms should be also used as a treatment measure for strabismus. After treatment with the methods above, subsequent phases are performed. Among the methods relevant to these phases, there are two that involve active use of prisms, the method for restoring the stability of fusion, and the method for developing binocular vision and fusional reserve with the help of biprism [51, 52]. The latter method was modified by researchers from the Filatov institute. The main principle of the modification is the use of Bagolini striated glasses with a minimum dissociation effect in an attempt to create the treatment conditions that are as close as possible to normal conditions of visual perception [53]. The treatment with the method above contributed to restoration of binocular vision for distance and for near in 66.7% and 96.7% of patients, respectively.

Conclusion

Prismatic correction is a major type of conservative treatment for strabismus which contributes to a gradual decrease in strabismus angle and development of binocular vision under normal conditions of visual perception of space. It does not pretend to be a substitute for surgery in many cases, but it can assist in improving the efficacy of surgery. Consequently, if started early, prism therapy in combination with subsequent surgical treatment enables making a child healthier at the pre-school age period, when binocular vision is most commonly developed.

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The authors certify that they have no conflicts of interest in the subject matter or materials discussed in this manuscript.