Literature Review

Use of prisms in ophthalmology: a review. Part 2. Use of prisms in heterophoria, nystagmus, and visual nervous system disorders

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Prism correction can be helpful not only for patients with strabismus, but also for those with other eye conditions. In heterophoria, especially in the presence of asthenopic complaints, prisms can be used for compensation for latent strabismus and development of fusional reserves. Prisms can reduce an abnormal head posture and thus normalize the posture of a child in jerk nystagmus. Base-out prisms are prescribed to induce divergence and stimulate fusional convergence for decreasing the amplitude of nystagmus and thus improving visual acuity in patients whose nystagmus is suppressed by viewing a near target. In patients whose nystagmus is worse during near viewing, base-in prisms may help which induce divergence. Prisms can be helpful for eliminating diplopia in thyroid eye disease and are used for assessing the Accommodative Convergence to Accommodation (AC/A) ratio. They can be also helpful to shift the image from the affected fovea to the preferred retinal locus in patients with absolute central scotoma and eccentric gaze fixation and to expand visual fields in patients with hemianopia and retinitis pigmentosa. Ophthalmologists should bear in mind that the above conditions can be treated with prisms, and apply prism correction widely in their practice.

Keywords:
prisms, heterophoria, nystagmus, diplopia

1. Use of prisms for evaluating eye muscle balance and treating eye muscle imbalance disorders

A. Concepts of orthophoria and heterophoria

An individual is said to have normal eye muscle balance if his/her eyes are directed straight ahead, with their vertical meridians being in upright position, when binocular fusion is disrupted by occluding one eye [1]. This condition is named orthophoria (in Greek, orthos means ‘‘straight’’ or ‘‘correct’’, while phoria means “carrying” or “bearing”). If the fusion mechanism is well-developed and the deviation slight, visual alignment may be maintained in normal circumstances by a continued effort of fusion: the strabismus is then latent and can only be made manifest when fusion is made impossible (as by covering one eye). This condition is called heterophoria (in Greek, heteros means ‘‘other’’ or ‘‘different of’’). An individual may be diagnosed with heterophoria if only (s) he is completely capable of binocular vision [1].

According to Kanski [2], heterophoria implies a tendency of the eyes to deviate when fusion is blocked (latent squint). Slight heterophoria is present in most normal individuals and is overcome by the fusion reflex. This is called compensated heterophoria. When the fusion amplitudes are inadequate to control deviation, there is decompensated heterophoria. It is usually associated with such symptoms as discomfort in binocular vision and diplopia. Heterophoria may be a cause of migraine, vegetative dystonia and visual fatigue [3].

Noorden and Campos [4] noted that in heterophoria there is a **relative** deviation of the visual axes held in check by the fusion mechanism, whereas in heterotropia there is a **manifest** deviation of the visual axes. The relative position of the visual axes is determined by the equilibrium or disequilibrium of forces that keep the eyes properly aligned and of forces that disrupt this alignment. Clearly, the fusion mechanism and its anomalies are involved in some manner in producing comitant heterotropias [4].

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The system regulating the motion of the eye consists of (a) the adduction portion (the afferent system) that transmits sensory information related to the position of the eye and (b) abduction portion (the efferent system) that is responsible for the motion. The main functions of the neural control of eye movements are enabling the direction of the eye to the visual target, maintaining the binocular vision, and finding the location of the visual target in space [5].

It has been reported that heterophoria can be classified pathogenetically, by the amount of latent deviation, and by the amount of compensation of binocular vision apparatus [6, 7].

Heterophoria may be classified according to the direction of the visual axes when the eyes are dissociated. Esophoria is an inward deviation; exophoria, an outward deviation; right hyperophoria, upward deviation of a right visual line; left hyperophoria, downward deviation of a left visual line; and cyclophoria, a globe rotation around the anteroposterior axis. In addition, excyclophoria is a temporalward rotation of the top of the vertical meridian during dissociation, whereas encyclophoria is a nasalward rotation of the top of the vertical meridian [1].

Mild heterophoria is common and seen in 29% to 80% of healthy individuals [8, 9, 10, 11]. Serdiuchenko [8] has reported on the results of a study of eye muscle balance using a modified Meddox scale containing not only digits, but also the pictures understandable to children, in 100 children aged between 4 to 7 years having visual acuity and refractive error within normal ranges for their age. Of these children, 64% were found to have orthophoria at distance, and 71%, orthophoria at near. Esophoria was the most common type of heterophoria (with 30% of children exhibiting esophoria at distance and 19%, esophoria at near), and in most cases, did not exceed 6 prism diopters. Kříž and Skorkowska [11] aimed to establish the prevalence of distance associated heterophoria in a sample of 170 clinical subjects aged 15-78 years with an average age of 40.7±16.62 years. All the participants had best-corrected visual acuity better than 20/25 and stereopsis ≤60 second of arc. The occurrence of distance associated heterophoria was found in 71.2% of participants. Of the total, 36.5% of the cases had esophoria (EP), 9.4% EP and hyperphoria, 10.6% exophoria (XP), 7.1% XP and hyperphoria, 7.6% hyperphoria, and 28.8% orthophoria. There was no correlation observed between the amount of distance associated heterophoria and age. There was no effect of the type and amount of a refractive error on the amount of distance associated heterophoria.

Much attention in the literature has been given to the clinical features and diagnostic evaluation of heterophoria [1, 12-19]. Heterophoria assessment is typically performed at distance (5-6 m) and at near (33-40 cm). Heterophoria measurements can be performed using a tangent scale with a source of light in the center and a Maddox rod [1, 8]. A method using a KK-42 set of prismatic strabismus compensators (on the basis of microprisms ranging from 0.5 prism diopters to 30 prism diopters) has been proposed to improve Maddox rod-based measurements of heterophoria [12].

Heterophoria is most commonly assessed at near, because its symptoms (visual fatigue) are usually manifested at near. Vertical line with a dot can be easily used for this purpose. A method for measuring horizontal heterophoria by displacing an image vertically with a prism is based on the fact that, with a six to ten-diopter prism base-up or base-down placed in front of the eye, the patient cannot overcome the prism strength, and exhibits vertical diplopia. With the prism base-down placed in front of the eye, the patient either sees the second line with a dot as a continuation of the first line, or the image of the second line may be displaced to the right or to the left, with this image being on the side of the prism for esophoria, and on the contralateral side for exophoria. This indicates the presence of horizontal heterophoria which may be neutralized by placing a second prism base in or base out. The degree of esophoria or exophoria is reflected by the power of the horizontal prism that accurately makes the two images aligned along the vertical line (i.e., produces a single line with two dots) [1].

A modified Howell test was developed by Kriuchko [20], with different bands of the scale marked by colors to indicate normal, allowed and pathological phoria values. In addition, exophoria values are denoted with "-" sign, while esophoria values, with "+" sign, enabling easy calculation of the Accommodative Convergence to Accommodation Ratio (AC/A). Another convenient feature is that the above scale is placed on a conventional occluder for acuity testing. Therefore, this modified test may be used not only for the quantitative assessment of near phoria in prism diopters, but also for qualitative assessment, which is important today, with many people working in the professions that require a high near visual load for a long time. The author, however, reviewed other studies [21] and noted that the the issue of scale calibration is still controversial and requires further research.

B. Use of prisms for treating heterophoria in the presence of asthenopic complaints

Mild heterophoria (3-4 prism diopters or less) commonly does not cause asthenopic complaints and is detected by accidental examination. More severe disease can cause asthenopic complaints like headache, blurring of vision, and/or double vision of letters. These complaints are especially common in young individuals who are active computer users. These patients should have a comprehensive eye examination, including not only near and far uncorrected visual acuity and near and far best-corrected visual acuity, but also refractometry (under cycloplegic conditions, if required), ocular media and fundus examination, ocular motility and convergence, with a special emphasis on the evaluation of heterophoria and fusional reserves. If fusional reserves are found to be inadequate, a patient should have a course of synoptophore and/or prism treatment aimed at the development of negative fusional reserves for esophoria and positive fusional reserves for exophoria [1]. In case of vertical heterophoria, Sergievskii recommends developing left suprafusional reserve for right hyperphoria, and right suprafusional reserve for left hyperphoria [1]. However, orthoptic exercises are sometimes contraindicated in emaciated individuals, neurasthenics, and those suffering from migraine or sinus diseases [22]. Prismatic lenses should be prescribed to correct decompensated heterophoria if orthoptic treatment is unsuccessful [22, 23]. Base-in prisms are prescribed for the treatment of exophoria, and base-out prisms, for the treatment of esophoria. In vertical phoria, the prism is placed with its base at the side contralateral to deviation of the eye. Avetisov and colleagues [23] believe that vertical heterophoria should be compensated for as much as possible. Vertical prisms are useful in the permanent or temporary alleviation of asthenopic symptoms arising from a vertical misalignment of the visual axes [24]. Methling and Jaschinsky [25] reported on an improvement in contrast sensitivity after wearing prisms (for at least two weeks) to correct heterophoria.

Spectacle correction for the refractive error may be sufficient for treating a patient with asthenopic complaints in the presence of refractive error. Spheroprismatic glasses, cylinder-prismatic glasses, or sphero-cylinder-prismatic glasses may be helpful if spectacle correction (without prism) for refractive error is not sufficient for the relief of asthenopic complaints. In recent years, combined microprism lenses have demonstrated good performance. A combined microprism lens is composed of a refraction lens tightly soldered with a microprismatic component in such a way that prism relief lines are positioned inwards. This microprism lens is processed properly and placed in the glasses frame [26].

Since a variety of other defects can lead to asthenopic complaints, a causal relationship with heterophoria can be assumed only after a thorough differential diagnosis. Prism spectacles or eye muscle surgery for heterophoria should be recommended only after prism trials in free space [10].

C. Artificial heterophoria

Induced prism in spherical or spherocylindrical spectacle lenses, which may result from inadvertent displacement of optical centers, may cause heterophoria, leading to patient complaints of diplopia, with diplopia usually varying with gaze direction. To differentiate the above condition from extraocular muscle paresis, it is first of all necessary to check the optical centers of spectacle lenses for the absence of their inadvertent displacement [1].

2. Use of prisms for calculating the Accommodative Convergence to Accommodation Ratio (AC/A)

The synkinesis between accommodation and convergence has important physiologic effects on binocular vision in near fixation, and an understanding of this role is essential in the study of comitant strabismus [4]. Measurements of the AC/A ratio are required in different forms of accommodative esotropia; exotropia; different forms of heterophoria, and refractive errors [15, 16, 22, 27-30]. Ratio can be determined using the heterophoria method; gradient method; graphical method; calculation method; fixation disparity method, and haploscopic method.

The heterophoria method is one of the most common. In 1960, Morgan [27] suggested to determine accommodative convergence (AC) using the following formula:

$$AC = (IPP \times 100)/a - Hf + Hn$$

where

IPP is interpupillary distance expressed in millimeters,

a is distance from the eye to near fixation point (333 mm)

100 is a coefficient used for expressing the AC/A value in prism diopters

Hn is near phoria (esophoria is plus and exophoria is minus) in prism diopters;

Hf is far phoria (esophoria is plus and exophoria is minus) in prism diopters.

The AC/A ratio is determined by dividing the AC value by 3.0 D for accommodation:

$$AC/A = AC/3.$$

A disadvantage of this and similar methods is the presence of systematic errors, i.e., no allowance is made for the fact that some accommodation as well as some convergence is being used when the gaze is transferred from an infinitely far object to an object at a distance of 5 m. In so doing, an individual uses 0.2 D-accommodation, whereas the amount of convergence used depends on his interpupillar distance (IPP). Thus, when viewing and object at a distance of 5, the amount of convergence used is 1 prism diopter for a IPP of 50 mm; 1.2 prism diopter for a IPP of 60 mm; and 1.4 prism diopter for a IPP of 70 mm [30]. Pospelov believes that the presence of some convergence at the 5-m distance resulting in a high systematic error (as high as 6.7% of the AC/A ratio value) should not be ignored. He performed relevant recalculations, and proposed the following formula for calculating the value of AC/A ratio:

$$AC/A = (0.28 \times IPP - Hf + Hn)/2.8 \text{ [prism diopter/diopter]}$$

A simple comparison of the deviation in distance and near fixation is commonly used in clinical practice to estimate the AC/A ratio [4]. If the two measurements are equal, the AC/A ratio is said to be normal. Normally, the AC/A ratio equals 3Δ to 5-6Δ of accommodative convergence for each diopter of accommodation. If the near measurements in an esotropic patient are greater by 10Δ or more, the AC/A ratio is said to be abnormally high [4].

The difference between the deviation in distance and near fixation is of great practical importance in assessing the degree of comitant strabismus in patients with esotropia or exotropia. Theoretically, the expected "ideal" AC/A ratio is when the convergence requirement is fulfilled by accommodative convergence. In a population with a normal sensorimotor system, the mean of the AC/A ratio is somewhat over half the interpupillary distance expressed in centimeters [4].

In the gradient method [4, 29], the change in the stimulus to accommodation is produced not by a change in viewing distance but by means of minus lenses. For a given fixation distance, minus lenses placed before the eyes increase the requirement for accommodation. It is assumed that -1D lenses produce an equivalent of 1D of accommodation, whereas +1D lenses relax accommodation by 1D, and that the accommodative response to the lenses (and therefore the accommodative convergence produced) is linear within a certain range. For a given fixation distance the AC/A ratio inferred from the effect of ophthalmic lenses may be readily ascertained from the simple formula:

$$AC/A = (\Delta 1 - \Delta 0)/D,$$

where $\Delta 0$ is the original deviation, $\Delta 1$ the deviation with the lens, and D the power of the lens.

The AC/A ratio computed by the heterophoria method is usually larger than the one obtained by the gradient method, mainly because of the effect of proximal convergence. For clinical purposes it suffices to measure the deviation with the eyes in primary position at a fixation distance of 33 cm in the patient fully corrected and then to repeat these measurements after the addition of +3.00D and -3.00D lenses [4].

Other methods for determining the AC/A ratio (see above) are not commonly used in clinical practice.

3. Use of prisms in nystagmus

Prisms are used for two purposes in the treatment of nystagmus: (1) to improve visual acuity and (2) to eliminate an anomalous head posture [4, 31, 32].

A. Use of prisms for improving visual acuity

AA. Induced convergence

In patients whose nystagmus is suppressed by viewing a near target, convergence prisms will often improve vision. Base-out prisms are prescribed to stimulate fusional convergence, which may be effective in decreasing the amplitude of nystagmus and thus improving visual acuity. The dampening of nystagmus allows "clear vision at a glance," removing the necessity for increased visual concentration and thereby avoiding intensification of the nystagmus resulting from that heightened fixation [31]. Normal binocular vision is a prerequisite of the use of prisms base-out since fusional convergence in response to prism-induced temporal retinal disparity cannot be expected in patients without fusion [31]. Seven prism-diopter base-out prisms are the most commonly prescribed for nystagmus [32].

AB. Induced divergence

Some patients with acquired nystagmus and in patients whose nystagmus is worse during near viewing, base-in prisms may help which induce divergence [31, 32].

B. Moving the null point

Prisms with base opposite to preferred direction of gaze may be helpful in correcting the head posture, with the null zone of the nystagmus shifted to the primary position. For example, in a patient with a head turn to the right, the null zone is in levoversion (i.e., the direction of gaze is to the left), and a prism base-out before the right eye and base-in before the left eye will be helpful in correcting the abnormal head posture. Prisms base up (if the null zone is in infraversion, with the chin elevated) or prisms base down (if the null zone is in isupraversion, with the chin depressed) can be used to decrease the amplitude of vertical nystagmus [32]. A combination of vertical and horizontal prisms can be used when the null zone is in an oblique position of gaze [31]. Prisms of sufficient power to shift the neutral point of nystagmus to correct a compensatory head posture are rarely tolerated. However, they may be useful preoperatively for a diagnostic trial [4, 31]. In the opinion of Kalaivani [31], the results of surgery for head turn in nystagmus can be reasonably well predicted on the basis of the patient's response to prisms, and a postoperative residual head turn may be alleviated further with prisms.

4. Use of prisms in thyroid eye disease

In thyroid eye disease complicated by mechanical strabismus and diplopia, ocular motility is limited in one or more directions of gaze, and prisms may be helpful for diplopia in these patients, with the prism power usually being less than the power that determines the angle of strabismus due to increased fusion amplitude [32].

5. Use of prismatic spectacles in bed patients

A reading individual normally holds his head upright (e.g., when working on computer, with the vertical axis of the globe being upright) or slightly tilted forward (e.g., when holding a book in his hands, with the vertical axis of the globe being 10 to 20 degrees inclined forward with respect to the vertical). When a bed patient has to read while being flat on his back and he holds a book at his waist, his globes are tilted sharply down, with excessive strain of the inferior rectus muscles leading to fast visual fatigue. In this case, it will be helpful to place prisms base-down in both eyes, with these prisms changing the direction of the image falling in the eyes in such a way that the patient maintains a correct position of the eyes in the orbits to enable visual comfort [23].

6. Use of prisms in low vision and eccentric fixation

Prisms can be used in patients with bilateral absolute central scotoma present for a long time in order to shift the image from the affected fovea to the preferred retinal locus (PRL). With this in mind, two identical high power (usually > 15 prism diopters) prisms are placed on the patient's spectacles, with the prism base directed into an eccentric gaze position. The prisms help these patients in utilizing and maintaining the PRL. They also enable improved patient's socialization, making his gaze more direct during interpersonal communication [32].

7. Use of prisms in patients with visual field defects

High-power Fresnel prisms have been found to be effective in expanding the visual field in patients with left or right hemianopia. To expand the upper quadrant of the field, a high power prism segment (30-40delta) is placed base-out across the upper part of the spectacle lens, on the side of the loss [32, 33]. In addition, prisms can be used for expanding the visual field in patients with retinitis pigmentosa. Segmented 20-prism diopter Fresnel prisms are placed around the visual axis and applied to the carrier lens with prism base toward the rim of the frame. This approach to the treatment of patients with retinitis pigmentosa and a central visual field of less than 10 degrees diameter was applied in a study by Somani and colleagues in 2006. They concluded that this method for the optical treatment of hemianopia was found to be effective in expanding the field, improving contrast sensitivity and helping patients' mobility [34].

Conclusion

Prism correction can be helpful not only for patients with strabismus, but also for those with other eye conditions like heterophoria, especially in the presence of asthenopic complaints (for the development of fusional reserves and compensation for latent strabismus); to assess the AC/C ratio; to eliminate an anomalous head posture in patients with nystagmus, eliminate diplopia in thyroid eye disease; to shift the image from the affected fovea to the preferred retinal locus in patients with absolute central scotoma and eccentric gaze fixation; and to expand visual fields in patients with hemianopia and retinitis pigmentosa. Ophthalmologists should bear in mind that the above conditions can be treated with prisms, and apply prism correction widely in their practice.

Conflict of Interest. *The author declares that there are no conflicts of interest that could influence his or her opinion on the subject matter or materials discussed in this manuscript.*

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Case Reports

Performing DALK complicated by Descemet's membrane macroperforation in keratoconus without conversion to penetrating keratoplasty: a case report

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We report a case of successful deep anterior lamellar keratoplasty (DALK) for kearatoconus in the presence of intraoperative Descemet's membrane (DM) macroperforation in a 10-year boy. Intraoperative optical coherence tomography–guided femtosecond laser-assisted DM separation from the periphery to the center facilitated keeping the anterior chamber angle open and avoiding a subsequent increase in intraocular pressure. In addition, the size of the graft was made 0.4 mm larger that the size of the trephination hole, which enabled fitting of the graft margins and trephination margins, whereas precise deep femtosecond laser corneal dissection enabled (a) preventing a shock wave effect from the laser pulses and (b) DM adherence to the stroma of the graft. At 5 months after surgery, uncorrected visual acuity (UCVA) was 0.5; keratometry values OD were R1, 7.67 mm; K1, 44.0 D; R2, 7.30 mm; K2, 46.2 D; Rm, 7.48 mm; Km, 45.1 D; and Astig, 2.2 D. Anterior chamber angle was 41.4º. The DM adhered well to the donor stroma, the DM defect was practically not visualized on imaging, and endothelial cell density was 2719 cells/mm2 in the operated eye. At 7 months after surgery, the patient's UCVA was 0.6 OD and corrected visual acuity with a spherical equivalent of +3.0 D was 0.9.

Keywords:
deep anterior lamellar keratoplasty, Descemet's membrane macroperforation

Keratoconus is a non-infectious degenerative condition with lesions of the corneal stromal collagen matrix in which the normally round and regular shape of the cornea progressively thins and bulges until it is a cone-like, irregular shape. The reported incidence varies from 1:2,000 to 1:500,000 [3].

Corneal transplantation (or keratoplasty) is still the only treatment for late-stage keratoconus. Deep Anterior Lamellar Keratoplasty (DALK) is a widely recognized treatment for keratoconus, and makes it possible (a) to avoid the complications (e.g., postoperative glaucoma) characteristic of penetrating keratoplasty (PK) [3, 4, 5] and (b) to preserve patient's endothelial cells.

The endothelial cell loss (ECL) is more intensive during 6 months after DALK (10%), and remains almost constant thereafter until month 12, whereas PK patients exhibit an ECL of 33-43% over 12 months. However, DALK is a more difficult procedure to perform than PK, and intraoperative Descemet's membrane (DM) tear (microperforation or macroperforation) can occur with DALK, requiring conversion to PK. The rate of conversion from DALK to PKP due to loss of the integrity of DM varies from 2.9% to 23% and depends on the surgeon's experience, ability to successfully bare the DM, and indication for keratoplasty [3, 5].

The case becomes even more complicated when a large DM tear occurs at an early stage of stromal dissection, before complete baring of DM or before reaching a satisfactory pre-descemetic plane. Dissecting the remaining thick residual stromal layer will apply more traction forces on the edges of the tear making the conversion to PKP very likely [1].

The management of DM perforation includes intracameral air tamponade, stromal patching, fibrin glue and suturing of the defect [1, 2, 5].

Most DALK surgeons are now in agreement that DALK can still be successfully completed with almost all microperforations (less than one quarter of the cornea) using air/gas tamponade for DM apposition to the donor cornea. There is no, however, agreement on whether DALK can still be successfully completed with macroperforations.

Some authors believe that in cases where the surgeon encounters macroperforations (greater than one quadrant of the cornea), it may not be easy to complete the dissection of the posterior lamella fully up to the Descemet's or pre-Descemet's region, and, in such cases, better visual and refractive outcomes are achieved by converting