CONTACT LENS

Prismatic Effects of Iseikonic Spectacle-Contact Lens Telescopic Systems

A. Remole*

Abstract

The method of correcting aniseikonia in unilateral aphakia by means of a spectacle-contact lens combination has been described in detail in the literature. This article addresses one consequence of such corrections, namely, the induced prismatic effect. A comprehensive formula is developed to show how this effect compares with the aniseikonia corrected.

Introduction

When the crystalline lens is removed in cataract surgery, the optical constants of the eye change radically. A higher power aphakic spectacle correction pulls the principal planes forward, increasing the equivalent focal length of the combined optical system. Because the retinal image is proportional to the second focal length of this system, it becomes much larger than in the normal eye, usually by about 25%[1].

When the aphakic eye is corrected with a contact lens, the principal planes move forward to a lesser extent. However, even with this type of correction, they are translated a rather significant amount from within the aqueous chamber to become situated approximately in the plane of the contact lens. The result is that the retinal image is still magnified considerably, about 7.5% in the standard eye. When only one eye is aphakic, this magnification difference will result in a very significant amount of aniseikonia.

Enoch[2,3] developed an excellent method of correcting aniseikonia in unilateral aphakia. Essentially, it consists in placing a reversed Galilean telescope before the aphakic eye, incorporating the "objective" of the telescope in a contact lens, and the negative "eye piece" in a spectacle correction. In addition to the power representing the "objective", the contact lens would contain plus power to correct the ametropia of the aphakic eye. Conversely, a conventionally oriented telescope can be prescribed for the phakic eye, designed to enlarge the retinal image to match that of the aphakic eye. The phakic eye, even if emmetropic, would then have to be fitted with a contact lens to contain the "eyepiece." Also, the iseikonic correction can be distributed between these two types of spectacle-contact lens telescopes.

The purpose of this paper is to illustrate and discuss a potential problem inherent in this method of correcting aniseikonia. The literature already contains detailed accounts of the principles pertaining to the procedure. Nevertheless, before we can proceed, it will be necessary to review its most salient features.

In Fig. 1, the portion of the contact lens representing the objective of the Galilean telescope has been shown, for illustrative purposes, as separate from the portion of the contact lens correcting the ametropia. For simplicity, the thickness of the spectacle lens and contact lens has been ignored. The spectacle lens and the "objective" portion of the contact lens can then be treated as front and back surfaces of a lens whose thickness is *t* and refractive index, 1.000 (air). The spectacle magnification produced by this "air-lens" can be found by the conventional formula:

$$SM = \left(\frac{1}{1 - \frac{t}{n}F_1}\right)\left(\frac{1}{1 - dF_v'}\right)$$

where, in general:

SM = spectacle magnification
t = thickness of lens
F_1 front surface power
d = vertex distance
F_v' = back vertex power of lens

The two factors are the well known "shape" and "power" factors, respectively.

If we apply the general formula to the spectacle-contact lens Galilean telescope, n becomes 1.000, and t becomes the distance between the two lenses, say 15 mm. F_1 in the formula becomes identical to the back vertex power of the thin lens. Since we are

*B.F.A., O.D., M.S., Ph.D., Professor
School of Optometry, University of Waterloo

designing an afocal system, F_V' becomes zero. If we let the back vertex power of the required spectacle lens "eye piece" = S_V', then:

$$\left(\frac{1}{1 - t(S_V')}\right)\left(\frac{1}{1 - d(0)}\right) = \frac{1}{M}$$

where M is the compensating magnification required before the phakic eye. Solve for S_V':

$$1 - t(S_V') = M, \text{ and, } S_V' = \frac{1 - M}{t} \quad \text{(I)}$$

The question might arise why $\frac{1}{M}$ has been used in the development of the equation rather than -M. If we find, by measuring the aniseikonia, that the phakic eye needs, say, 7.5% to bring about iseikonia, then it is a good clinical approximation to assume that the same effect can be achieved by placing a -7.5% telescope before the aphakic eye. Using this value in the above derivation would, in fact, have resulted in an approximate but workable formula. However, it is more accurate to specify the power of the reversed telescope as $\frac{1}{1.075}$ = 0.9302 or -7.00%. In the development of the formula, we have used this more exact relationship.

Illustrative Example

By testing a patient with unilateral aphakia, it is found that 7.5% magnification is needed over the phakic eye to produce iseikonia. If the vertex distance is 15 mm, find the constants of an iseikonic reversed Galilean spectacle-contact lens telescope.

From formula (I), the back vertex power S_V' of the required minus spectacle lens is:

$$S_V' = \frac{1 - 1.075}{0.015} = -5.00\text{D}.$$

The effective power of this lens at the cornea is:

$$\frac{-5.00}{1 - \left(\frac{0.015}{1.000}\right)\left(-5.00\right)} = -4.65 \text{ D}.$$

To make the spectacle-contact lens afocal, +4.65 D will therefore have to be added to the ametropia contact lens correction.

If the patient were previously emmetropic, a zero back vertex power spectacle lens is, of course, placed before the phakic eye. The procedure for prescribing a conventionally directed Galilean telescope before the phakic eye is similar to that set out above and does not need to be dealt with in this review.

Dynamic Aniseikonia

When aniseikonia is induced by a contact lens prescription, the two ocular images differ in size. However, if aniseikonia is induced by an anisometropic spectacle correction, not only is there an ocular image size difference, but in addition, because the spectacle lenses do not follow the eyes, differential prismatic effects are constantly produced. When both eyes look up, one eye has to move farther than its mate because the primary image formed by the spectacle lens in the far point plane is larger than the other. When the eyes look downwards, the same eye now has to rotate farther downwards than its mate (Fig. 2). This problem exists in all meridians.

The effect was first described by Jackson[4] and has been investigated by many others. He proposed that the discomfort experienced in aniseikonia springs from this effect rather than from the differences in retinal images. Von Rohr[5] and Erggelet[6] drew similar conclusions. On the other hand, Ogle[7] considered the effect of secondary importance to the difference in ocular images. He based his conclusion on evidence that the oculomotor mechanism at least partially adapts to the prismatic effects (Ellerbrock and Fry[8]; Cusick and Hawn[9]). Ellerbrock[10] and Allen[11] showed that there is ample ability to adapt to vertical prism. Henson and Dharamshi[12] investigated the prismatic effect caused by anisometropic spectacle corrections in all meridians. They found that for an anisometropia of up to 4.50 D, the oculomotor system was able to adapt if given enough time.

However, when we consider differential prismatic effects in anisometropia, we have a situation in which these effects are constantly changing across the fixation field. We have the choice of specifying the different prismatic effects at given distances from the optical centre of the lens, or, we can develop an expression that will yield a single value for the entire fixation field. This can be achieved if we realize that the prismatic effect is simply a consequence of the difference in sizes of the primary images formed by the lenses in the far point planes. This concept of the prismatic effect reveals an unmistakable similarity with ocular image differences in aniseikonia. We have chosen the term *dynamic aniseikonia* to designate the prismatic effect expressed in terms of the size difference between the primary images. *Dynamic* pertains to the constant motion of the eyes as they fixate the various points in the stationary primary image. In contrast, we use the term *static aniseikonia* to refer to ocular image differences, *static* referring to a theoretically stationary retinal image.

The term *dynamic aniseikonia* has several advantages aside from the primary purpose of expressing prismatic effects in magnification terms. Thus, it emphasizes that the effect occurs in all meridians, not just at the reading point. Also, it eliminates the common notion that the prismatic effect is incidental to the prescription. Dynamic aniseikonia is a magnification difference that describes the entire fixation field at once, whereas prismatic effect must be stated as a different value for every location of the spectacle lens.

In the following, we shall determine the amount of dynamic aniseikonia that can be induced by a contact-spectacle lens reversed Galilean telescope.

Dynamic Aniseikonia Induced by a Contact-Spectacle Lens Iseikonic Unit

The reversed Galilean telescope described above can be designed to eliminate static aniseikonia completely. However, since the spectacle lens is stationary, it will induce dynamic aniseikonia that did not previously exist. We have traded the static aniseikonia for a certain amount of dynamic aniseikonia, the magnitude of the latter depending on the dioptral difference between the two spectacle lenses. Enoch, in his pioneer article[2], was fully aware of the effect and gave recommendations how to treat it. However, because of the necessary emphasis in his article on the telescopic correction, relatively little space was devoted to the prismatic effect.

Assume a hypothetical case where a -5.00 D spectacle lens is combined with its appropriate contact lens "objective" before the aphakic eye, as in the above example. The spectacle lens is mounted 15 mm from the contact lens and 25 mm from the centre of rotation of the aphakic eye. An ideal iseikonic correction would result if the phakic eye happened to be -5.00 D myopic: if aberrations are ignored, neither dynamic nor static aniseikonia would be present.

Suppose, however, that the phakic eye is emmetropic and has been prescribed with a zero power balance lens. If the patient looks to the side, or up or down, 10 mm along the spectacle plane from the major reference point, a prismatic effect of 5^{Δ} would be produced (Prentice's rule). This is equivalent to an angular displacement of $\tan^{-1} 0.05 = 2.8624°$. The subtense of the semifield defined by 10 mm of eccentricity is $\tan^{-1} \frac{10}{25} = 21.8014°$. The corresponding field in object space is $21.8014° + 2.8624° = 24.6638°$. The resulting minification is therefore $\frac{21.8014°}{24.6638°} = 0.8839$. To offset the resulting magnification difference, the primary image seen by the phakic eye would need a magnification of $\frac{1}{0.8839} = 1.1313$. We have traded a static aniseikonia of 7.5% for a dynamic aniseikonia of 13%.

Approximately the same result can be obtained by adapting the general formula for the spectacle magnification to the centre of rotation. This is achieved by replacing the constant *d* with *s*, the distance between the lens and the centre of rotation, 25 mm in our example. Assuming for simplicity that one spectacle lens is of zero back vertex power, the ratio of the images in the far point planes, M_d, becomes:

$$\left(\frac{1}{1-\left(\frac{t}{n}\right)F_1}\right)\left(\frac{1}{1-s\,F_v'}\right) \qquad \text{(II)}$$

If the thickness of the spectacle lens is ignored:

$M_d = (1)\left(\frac{1}{1-0.025(-5.00)}\right) = 0.8888$, which yields a dynamic aniseikonia, DA (required iseikonic correction) of $\frac{1}{0.888} = 1.1251$, or 12.5%. The slight discrepancy with the previous value derives from the use of Prentice's rule in the former example.

A simple expression for the dynamic aniseikonia induced by the telescope can be derived from Fig. 3:

Ratio of far point images $= M_d = \dfrac{\text{Field of view produced by spectacle lens}}{\text{Field of view in object space}}$

The fields are approximately proportional to the tangents formed by y, the eccentricity, s, the stop distance, and s', the conjugate of the stop distance, tracing the light backwards from image space to object space. Thus:

$M_d = \left(\frac{y}{s}\right)\left(\frac{s'}{y}\right) = \frac{s'}{s}$, and, DA (required correction) =

$$\frac{1}{M_d} = \frac{s}{s'} \text{(III)}$$

$\frac{1}{s'} = \frac{1}{s} + F$ (Paraxial formula) Substituting in (III), we get:

$DA = s\left(\frac{1}{s} + F\right) = 1 + sF$ (IV) For a stop distance of 25 mm:

$$DA = 1 + \frac{F}{40} \qquad \text{(V)}$$

Applying (V) to the previous example:

$DA = 1 + \frac{-5.00}{40} = 1 - 0.125 = 0.8750$. Therefore, the magnification required before the phakic eye $= \frac{1}{0.875} = 1.1428$, or about 14%. The discrepancy between this value and that obtained previously results from substituting tangents for angles.

It must, of course, be borne in mind that the above expressions refer to the difference between the left and right lenses. If the lens before the phakic eye has a power other than zero, the difference between the two powers would apply as above.

Had we chosen to express the dynamic aniseikonia in terms of prismatic effects, we should need a graph or table showing the effect at the various points of the lens rather than a single value describing the entire lens. In this sense, the new formula is more comprehensive. Should we desire to convert the dynamic aniseikonia to its prismatic effect equivalent at a point on the lens, the following relationship can be used:

$d\ \Delta = \frac{c}{s}(DA - 1)$ (VI) where:

$d\Delta$ = differential prismatic effect
c = eccentricity in cm

Conversely, the dynamic aniseikonia can be calculated from the measured prismatic effect at a point in the lens as follows:

$$DA = 1 + \frac{d\Delta(s)}{c} \qquad \text{(VII)}$$

Having established a set of expressions for dynamic aniseikonia, we now turn to the spectacle-contact lens telescope discussed above. The induced dynamic aniseikonia can range from zero in the ideal case to a very large value. Figure 4 illustrates the increase in induced dynamic aniseikonia with difference in power between the spectacle lenses. This relationship, shown in the form of the diagonal straight line, is based on the approximate formula above (V). The horizontal line represents static aniseikonia of 7.5% as found with the standard eye. The grey horizontal zone represents the region within which most cases of aphakic aniseikonia would fall.[13]

Discussion and Conclusions

It is seen from the graph in Fig. 4 that, in the case of the standard eye, the dynamic aniseikonia becomes numerically equal to the static aniseikonia when the difference in power between the two spectacle lenses is 3.00 D. For a difference of 8.00 D., the dynamic aniseikonia becomes 20%, or almost three times as great as the static aniseikonia neutralized by the prescription.

It is to be noted that the graph is based on paraxial optics and therefore does not include the effect of prismatic aberrations. These aberrations generate a nonuniform magnification effect over and above the effect shown, that is, an exponentially increasing magnification or minification towards the periphery of the lens. This also applies to the prismatic effect, which deviates more and more from Prentice's rule away from the optical centre. The graph is, however, a good first order approximation to the induced dynamic aniseikonia in a spectacle-contact lens correction.

The overriding conclusion from the foregoing is that the dynamic aniseikonia induced by a contact-spectacle lens iseikonic telescope is of a much larger order than indicated by isolated calculations of the prismatic effect. This has become clear only after we have expressed size differences between primary images in the far point planes as magnification values rather than prismatic effects.

However, the criteria for evaluating and managing dynamic aniseikonia in a clinical setting differ from those pertaining to static aniseikonia. The seemingly large magnitudes of the induced dynamic aniseikonia do not necessarily detract from the usefulness of the spectacle-contact lens correction. As already has been pointed out in the foregoing, the oculomotor system has considerable ability to adapt to dynamic aniseikonia. Henson's data in particular[12], show that such adaptation occurs at least up to an eccentricity of about 20°, and at least for dioptral differences of up to 4.50 D, which corresponds to a dynamic aniseikonia of $1 + \frac{4.50}{40} = 1.1125$, or about 11%. At the Aniseikonia Clinic of the University of Waterloo, unilateral aphakics have been corrected successfully with the contact-spectacle lens telescope inducing a dynamic aniseikonia of up to 17%, even without the aid of a slab-off lens. These comments may remove much of the hesitation to prescribe such a correction that we may, inadvertently, have produced with our account of dynamic aniseikonia.

Nevertheless, many questions remain with respect to the clinical management of dynamic aniseikonia. Partly, this is because it has been deemed secondary to the static aniseikonia, and, partly, because it has been obscured somewhat by the application of Prentice's rule to a few selected locations on the lens.

One such question is that, although the oculomotor system adapts more readily to dynamic aniseikonia than the binocular perceptual system adapts to static aniseikonia, does this mean that visual comfort is also more readily achieved with the former? A study by Remole[13] shows that if equal amounts of dynamic and static aniseikonia (5%) are compared over the short term (5 min or less), before any considerable amount of adaptation takes place, dynamic aniseikonia is significantly more uncomfortable that static aniseikonia. It does not follow, of course, that dynamic aniseikonia will remain the more uncomfortable once adaptation has taken place. At the time of writing, we simply do not have the answer, although clinical experience seems to suggest that patients who adapt to dynamic aniseikonia are also comfortable with the situation.

We believe the separation of the effects produced by an anisometropic correction into static and dynamic aniseikonia will clarify the approach to further research in the area. A next logical step would be to compare the long term effect of the two kinds of aniseikonia on visual comfort.

While more information about dynamic aniseikonia is pending, it is advisable to approach the application of the spectacle-contact lens correction with extra caution when a large amount of aniseikonia is induced. This would include evaluation of the patient's binocular oculomotor performance and the possible application of slab-off lenses. After the fitting, a close monitoring of symptoms of dynamic aniseikonia, such as, for example, diplopia, would be in order. In general, a more thorough follow-up would be called for.

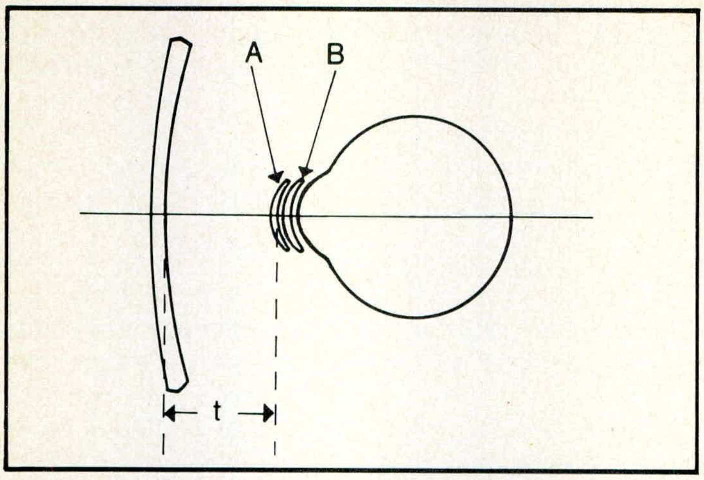

Fig. 1. Iseikonic reversed Galilean telescope prescribed for the aphakic eye in unilateral aphakia. A, "objective" portion of contact lens; B, ametropia portion of contact lens. For details, see text.

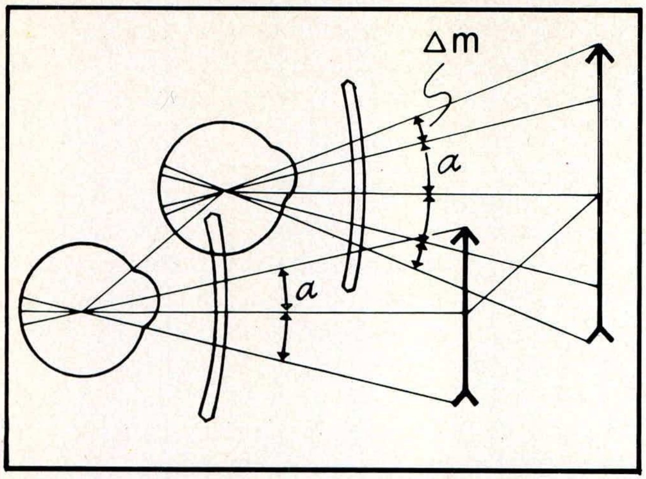

Fig. 2. Dynamic aniseikonia induced by an anisometropic correction. The eye presented with the larger image in the far point plane has to move an extra amount, Δ m, where m = magnification.

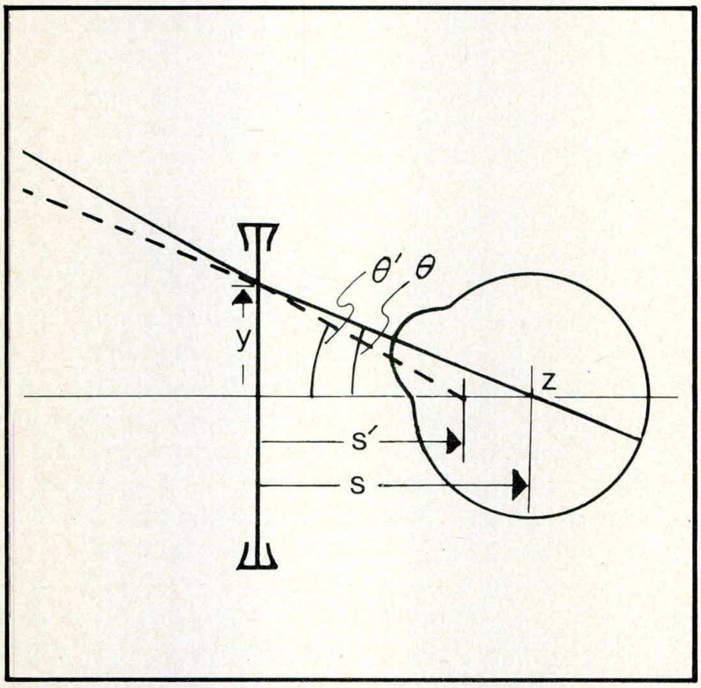

Fig. 3. Illustration used to derive the expression for dynamic aniseikonia. y, eccentricity of ray; s, stop distance; s', image of stop distance formed by the spectacle lens when the light is traced backwards from the centre of rotation (z) of the eye. Θ, field imaged by spectacle lens; Θ', conjugate field in object space.

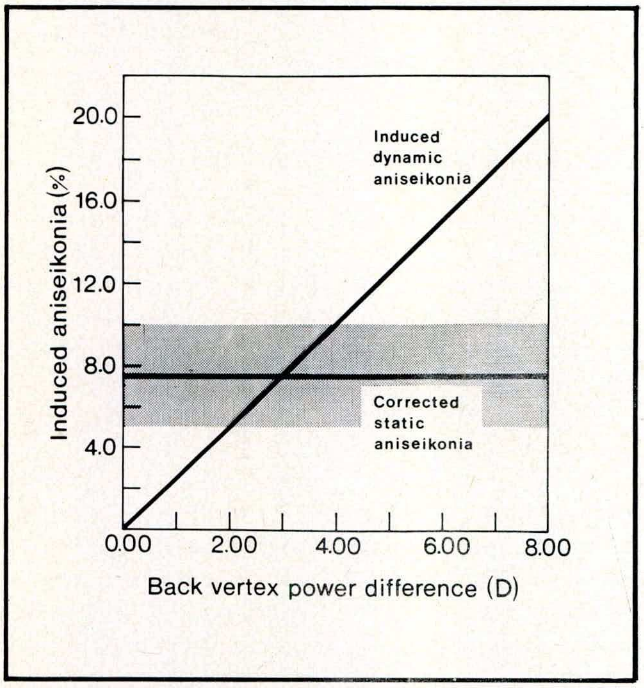

Fig. 4. Graph showing the relationship between the dynamic aniseikonia and the difference in power between the spectacle lenses used in the iseikonic telescope prescription. The induced aniseikonia refers to the required aniseikonic correction, for this is how aniseikonia is most often specified. For details, see text.

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