Planned myopic astigmatism as a substitute for accommodation in pseudophakia

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ABSTRACT

Patients with an implanted intraocular lens can be made nearly spectacle independent by increasing the depth of focus of the uncorrected implanted eye. In simple myopic astigmatism the visual acuity can be above 20/50 from far to near because the size of the blurred retinal image changes less than its shape as an object approaches the eye. For simple myopic astigmatism the change in corneal power must be included in the calculation of intraocular lens power. The change in corneal power induced by surgery is a spherocylinder with no spherical equivalent. The postoperative shape of the cornea can be predicted and intraocular lens power is calculated to make the flatter meridian emmetropic. The stronger meridian of the cornea is then myopic. In a series of 40 successive cases, the refractions and the measured depth of focus illustrate the application of these principles and the advantage of myopic astigmatism for the pseudophakic patient.

Key words: myopic astigmatism, intraocular lens power calculation, corneal power, emmetropia, ametropia, iseikonia, induced aniseikonia

Preoperative calculation of intraocular lens (IOL) optical power raises the problem of the optimal refraction in an eye without accommodation. Most surgeons advise emmetropia or a slight myopia as an optimal refraction. We have been looking for a method to increase the depth of focus and restore a degree of accommodation to the implanted eye. This can be achieved with a rigid IOL, if the implanted eye has slight myopic astigmatism. The visual acuity in uncorrected myopic astigmatism can be nearly constant from far to near. The blurred retinal image of a point light source is, in myopic astigmatism, the intersection of Sturm's conoid and the retina (Fig. 1). When one meridian of the implanted eye is emmetropic and the second meridian myopic, the retina is inside Sturm's conoid of astigmatism for all viewing distances from infinity to the near point of the myopic meridian. As long as the retina is inside Sturm's conoid the shape of the blurred retinal image, more than its size, will change for different fixation distances. Peters has shown that in phakic eyes with little accommodation a simple myopic astigmatism of 1.5D still allows an uncorrected far acuity of about 20/40 (Fig. 2).

The blur size in a myopic eye (Fig. 4) is minimal when the light source is at the far point. The size of the retinal blur increases rapidly as the light is moved closer to the eye. The shape of the blurred image for out-of-focus point objects is always a circle. In the astigmatic eye the size of the blurred image does not change as much as the object comes closer. There are two minimal blur sizes when the object of interest is at the far point of a meridian in the astigmatic eye.

We decided to aim at a slight myopic astigmatism as a postoperative refraction in implanted eyes, to make the patients spectacle independent for most of their activities. The increase in the depth of focus is achieved at the cost of a slight reduction in the uncorrected visual acuity compared to the emmetropic eye for distant vision.

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Fig. 1 (Huber). Schematic drawing of Sturm's conoid of astigmatism. The size of the blurred retinal image is defined by the intersection of Sturm's conoid and the retina. In myopic astigmatism, the conoid of astigmatism moves through the retina when the fixation distance changes from far to near. For a fixation distance at the far point of the myopic meridian, the shape of the blurred retinal image is first a line, then an ellipse or a circle, and then a line.

Pseudoaccommodation in myopia and myopic astigmatism

Fig. 3 (Huber). Path of the light rays and shape of the retinal image in an eye with a weak myopia (left) or a weak myopic astigmatism (right). In myopia for distant vision the image of a point light source is in front of the retina and is a blurred disk (A, left). The image is sharply focused on the retina when the object is at the far point of the myopic eye (B, left). For still nearer fixation distances the image is again a blurred disk (C, left). In the astigmatic eye, the image of a distant point (A, right) is a line. For an intermediate fixation distance the shape of the blurred image is the intersection of Sturm's conoid and the retina (B, right). The blurred image can be either an ellipse or a circle. When the object is at the far point of the myopic meridian, the image is again a line (C, right).

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SURGICAL TECHNIQUE

We used suture tension to achieve corneal astigmatism after cataract surgery. The induced astigmatism can be stable if permanent sutures are used. When the total change in corneal power is calculated from the power and orientation of both principal meridians before and after surgery,\(^8\) induced ametropia was always a spherocylinder combination with a very weak spherical equivalent (Fig. 5). An increase in corneal curvature near the 90° meridian is compensated by flattening the cornea in a meridian near 0°. Without a surgical keratometer we did not adjust the amount of astigmatism during surgery, but controlled the amount of surgical ametropia by cutting the corneoscleral nylon sutures in the steeper meridian in the postoperative phase. Astigmatism can be adjusted if there is some excess of astigmatism to start with. A plot of the surgical corneal ametropia over time (Fig. 6) shows that the effect of suture cutting is to reduce the amount of surgical ametropia along a line of equal spherical equivalents (A) and not along a vertical line (B) corresponding to a reduction of the astigmatism alone.

We have used this knowledge to predict the postoperative shape of the cornea after implantation, assuming an induced surgical ametropia of \(-1\) sph = \(+2\) cyl/90°. The weaker meridian of the predicted cornea is used to calculate the IOL power for emmetropia in that meridian. The steeper corneal meridian produces a simple myopic astigmatism. All calculations pertaining to lens calculation, aniseikonia calculation or to the addition of spherocylinders can be done quickly using a programmable calculator with a permanent memory (HP/41 C). The program used for the calculation of lens power is an improved version of the program published for the HP/65 calculator\(^9\) and is described in Appendix A.

Fig. 5 (Huber). Schematic drawing of the change in corneal curvature induced by cataract surgery. The increase in corneal power near the 90° meridian is compensated by a decrease in corneal curvature around 0°. The net result of surgery is the addition to the preoperative corneal power of a spherocylinder with no equivalent power.

Fig. 6 (Huber). The change in corneal power induced by surgery can be adjusted in the postoperative phase by cutting sutures. The induced ametropia, i.e. the difference between the pre- and postoperative corneal power, is plotted for different cases over time in the period during which sutures were cut to reduce astigmatism. The induced corneal ametropia is plotted as spherocylinder, with the sphere on the x axis and the minus cylinder on the y axis. The changes in induced ametropia follow a line A of equal spherical equivalent and approach a point of no induced ametropia, i.e. the preoperative corneal power. The changes in induced ametropia do not follow a line B equivalent to the induction of astigmatism in one meridian alone.
RESULTS

Postoperative measurements of visual acuity at different distances do show an increased depth of focus in patients with myopic astigmatism after lens implantation. If the postimplant refraction is mainly spherical (Fig. 7), there is a sharp increase in visual acuity at the far point. Visual acuity becomes more constant over distance as myopic astigmatism increases. The same is true for cases with a mixed astigmatism. However the best acuities and depth of focus are found in subjects with about $-0.75$D to $-3.0$D of simple myopic astigmatism (Fig. 8).

In a series of 50 successive implant cases, 40 patients had a visual acuity of 20/25 or better. Optical analysis was limited to these 40 cases, since refractive measurements are uncertain when visual acuity is reduced. Two-loop, capsularly fixated Binkhorst lenses were implanted. The post-operative spectacle refractions (Fig. 9) are plotted as spherocylinders: the open circles are cases where a higher ametropia was planned to avoid an excessive aniseikonia. Refractions were measured three months after implantation. The spectacles are clustered between two oblique lines with a spherical equivalent of 0 and $-2.0$D. The mean spherical equivalent of the cases planned for simple myopic astigmatism is $-0.79$D $\pm 0.6$D. Further changes in corneal astigmatism will move the spectacle power along the oblique lines of equal spherical equivalent as the spherical equivalent power of the cornea remains constant.

Patients with an intraocular lens and a weak myopic astigmatism do not wear their spectacles for most of their activities. They need a bifocal or progressive correction only for longer reading periods or for driving.

A printout of the program described in Appendix A may be obtained by writing directly to the author at the address shown on the bottom of the first page.

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Fig. 2 is redrawn with permission from the American Journal of Optometry (38:194, 1961).
REFERENCES


APPENDIX A

This program uses equations published by C.D. Binkhorst and G.L. van der Heijde; it is equivalent to the nomograms published by van der Heijde but easier to use and more precise. The program is also an improvement on the HP/67 program published by Huber and Binkhorst.

All numerical values must be given in millimeters or diopters. (The equations are valid for meter and diopter). The HP/41C needs one additional memory module to accept the 288 steps of the program, with an allocation of 20 registers for memory. The program can be used with or without the HP/82143A printer. With the printer all results are printed until the next input is requested. Without a printer the program must be started again after each output.

Intraocular Lens Power and Induced Aniseikonia

The program calculates intraocular lens power for emmetropia, ametropia or aniseikonia. It also calculates the induced aniseikonia or ametropia when one of both values is known. If the power of the implanted IOL is known, both induced ametropia and induced aniseikonia can be calculated.

The following data are needed to calculate the power of an intraocular lens: axial length of the operated eye, postoperative corneal power, postoperative depth of the anterior chamber, and desired postoperative ametropia. The program first calculates corrected corneal power (Equation 1) and then the intraocular lens power (Equation 2).

EQUATION 1:

\[ F_c' = \text{Corrected corneal power} = \text{corneal power plus the power of the spectacle in the plane of the cornea} = \]

\[ F_c + \frac{1}{F_s} - \frac{1}{d_1}, \]

where \( F_s \) = spectacle power;
\( d_1 \) = spectacle-to-cornea vertex distance (12 mm for the operated eye; variable for the fellow eye);
and

\( F_c \) = corneal power assumed for the total cornea (front and back surface), using keratometer readings from the front surface and the Littman refractive index of \( n = 1.332 \) for the total cornea.

EQUATION 2:

\[ FL = \text{Power of a plano-convex intraocular lens } 0.6 \text{ mm thick} = \frac{n}{L - d_2 - 6.02 \times 10^{-5}} - \frac{1}{F_c'} - \frac{d_2}{n}, \]

where the factor \(-6.02 \times 10^{-5}\) is a correction factor which depends on the shape of the intraocular lens and is the distance between the lens surface and the second principal plane of the intraocular lens. This value is valid for plano-convex lenses with an average thickness of 0.6 mm.

\( L \) = axial length (ultrasound length plus 0.2 mm for retinal thickness)
d₂ = postoperative anterior chamber depth (measured from corneal apex to anterior surface of the intraocular lens)

n = refractive index of aqueous and vitreous = 1.336

After calculation of IOL power, the program uses data for the fellow eye to calculate the aniseikonia induced by the implanted lens. Values needed are axial length, corneal power, spectacle (or contact lens) power, vertex distance, and optic depth. The last value is the distance from the corneal apex through the first two-thirds of the natural lens. The program first calculates the power of the cornea in the fellow eye as corrected by spectacle power and vertex distance (Fc’). It then calculates the total power of the fellow eye with correction (Equation 3). The posterior focal lengths of both the fellow and the operated eyes are calculated as the quotient of the refractive index (1.336) divided by Ftot for each eye. Aniseikonia is the difference between focal lengths, divided by the focal length for the fellow eye.

EQUATION 3:
Ftot = power of the eye with correction = \((1 - d₁ × Fs) × \left(\frac{n}{L - d₂}\right) × (1 - \frac{d₂}{n} × Fc')\)

Desired Aniseikonia
Using data for the fellow eye and the desired amount of postoperative aniseikonia, the program will calculate the spectacle power needed to give the implanted eye a total power (Fsi) equal to that of the fellow eye (Ftot) (Equation 4). This value is then used in Equations 1 and 2 to compute the intraocular lens power needed for the specific amount of aniseikonia.

EQUATION 4:
Fsi = total power of implanted eye = \(\frac{d₂}{n} × Fc - \frac{L - d₂}{n} × \left(1 - \frac{d₂}{n} × Fc\right)\)

Standard lens program
Corrected corneal power (Fc’) may be calculated using the power of the intraocular lens to be implanted, axial length, postoperative anterior chamber depth and the refractive index of aqueous and vitreous (Equation 5). The program then uses the spectacle power (Fs) and Fc’ to calculate resulting postoperative ametropia (Equation 6). This value is used to obtain the posterior focal length of the corrected system. If there are no data for the fellow eye in the computer’s memory, the program will stop at this point. If the values for the fellow eye are available, the program will calculate the posterior focal lengths of each eye and the resulting aniseikonia.

EQUATION 5:
Fc’ = corrected corneal power = \(\frac{n}{L - d₂ - 6.02 × 10^{-5}} × FL\)

EQUATION 6:
Fs = spectacle power = \(\frac{Fc' - Fc}{1 + (Fc' - Fc) × d₁}\)

Ametropia
In order to study the effect of various ametropias on intraocular lens power and aniseikonia, the postoperative spectacle power (Fs) is input. The program calculates the corrected corneal power in the operated eye (Fc’) and the intraocular lens power (FL). If data for the fellow eye are available, the program will automatically calculate focal lengths and resulting aniseikonia.