ARTICLE

Minimum amount of astigmatism that should be corrected

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PURPOSE: To evaluate how small amounts of astigmatism affect visual acuity and the minimum astigmatism values that should be corrected to achieve maximum visual performance.

SETTING: Optics Laboratory, University of Murcia, Murcia, Spain.

DESIGN: Case series.

METHODS: A wavefront sensor was used to measure astigmatism and higher-order aberrations (HOAs) in normal young eyes with astigmatism ranging from 0.0 to 0.5 diopter (D). Astigmatism was corrected for natural pupil diameters using a purpose-designed cross-cylinder device. Visual acuity was measured for high-contrast and low-contrast stimuli at best subjective focus with the natural and corrected astigmatism. From the aberrations, optical image-quality metrics were calculated for 3 conditions: natural astigmatism, corrected astigmatism, and astigmatism only (with all HOAs removed).

RESULTS: The study evaluated 54 eyes. There was no significant correlation between the amount of astigmatism and visual acuity. The correction of astigmatism improved visual acuity for only high-contrast letters from 0.3 D, but with a high variability between subjects. Low-contrast visual acuity changed randomly as astigmatism was corrected. The correction of astigmatism increased the mean image-quality values; however, there was no significant correlation with visual performance. The deterioration in image quality given by astigmatism higher than 0.3 D was limited by HOAs.

CONCLUSIONS: In most subjects, astigmatism less than 0.5 D did not degrade visual acuity. This suggests that under clinical conditions, the visual benefit of precise correction of astigmatism less than 0.5 D would be limited.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2014; 40:13–19 © 2013 ASCRS and ESCRS

Human vision is limited by the optical quality of the eye, especially by the presence of refractive errors (ie, defocus and astigmatism). Although the eye is also affected by higher-order aberrations (HOAs) such as trefoil, coma, and spherical aberration, in normal eyes these aberrations have a small impact on high-contrast visual acuity (HCVA).[1] However, in most persons with healthy eyes, uncorrected defocus and/or astigmatism significantly deteriorates the quality of vision. Spectacles typically correct both defocus and astigmatism with an accuracy of 0.25 diopter (D). With toric contact lenses, the lack of rotational stability reduces the efficacy of astigmatism correction.[2,3] As a consequence, many companies manufacture only contact lenses with cylindrical powers of 0.75 D or higher in steps of 0.50 D. On the other hand, despite recent advances in laser refractive surgery, the errors in the correction of astigmatism are approximately 0.50 D or higher.[4–6] Even standard ablations in photorefractive keratectomy and laser in situ keratomileusis to correct myopia can induce a mean astigmatism of approximately 0.50 D.[7] Therefore, the cylindrical correction of 0.75 D or less poses a dilemma for surgeons. In cataract surgery, toric intraocular lenses (IOLs) are an option for pseudophakic patients with astigmatic corneas[8,9]; however, the possible astigmatism induced by the corneal incision and the rotational and tilt errors during IOL positioning limit the efficacy of correcting small amounts of astigmatism. For this reason, the lowest commercially available cylindrical powers in IOLs exceed 1.00 D. A common option to minimize the visual impact of residual astigmatism is to target a spherical equivalent of 0.0 D.

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Published by Elsevier Inc.
0886-3350/$ - see front matter

http://dx.doi.org/10.1016/j.jcrs.2013.09.010

An important and not completely resolved practical question is to determine the minimum amount of astigmatism that has an impact on spatial vision. This would set a lower limit for practical correction, which is also affected by the accuracy of a particular correction procedure. Previous studies[10,11] found a significant reduction in visual acuity with from 0.25 to 0.50 D (depending on the visual chart used) of myopic astigmatism induced with trial lenses. However, the visual impact of small amounts of uncorrected astigmatism at best subjective focus remains controversial. This should be mainly determined by 2 aspects; that is, the optical deterioration in the retinal image[12] and the neural adaptation in the visual system.[13,14] Nevertheless, the astigmatism values to which the eye can adapt and the visual benefit of their correction have not been well determined.

In this context, we studied how small amounts of natural astigmatism (<0.5 D) and their correction affect visual acuity in a group of normal near-emmetropic subjects.

SUBJECTS AND METHODS

The study comprised healthy eyes of young subjects with astigmatism less than 0.5 D and defocus within −1.0 D to +1.0 D. The study followed the tenets of the Declaration of Helsinki. After receiving an explanation of the nature and possible consequences of the study, all subjects signed an informed consent form.

In all cases, optical aberrations and visual acuity for far were measured under natural viewing conditions (ie, no drugs were used to paralyze accommodation or dilate the pupil). The measurements were repeated 3 times; the mean value and standard deviation (SD) were calculated.

Optical Measurements and Astigmatism Correction

Wavefront aberrations were measured using a purpose-designed laboratory Hartmann-Shack wavefront sensor.[15] Zernike coefficients[16] were estimated and astigmatism was calculated and from the coefficients C(2,−2) and C(2,2). These astigmatism values were carefully corrected using a purpose-designed device that consisted of 2 rotating 0.25 D cylindrical lenses that change cylindrical power from 0.00 to 0.50 D depending on the rotation angle (α) between them. The combination gives a total cylindrical power of 0.5 × cos(α), and the orientation of the axis is adjusted by rotating the whole device. The angle α is changed in 4-degree steps, inducing power changes from 0.03 D when α is 86 degrees to nearly 0.50 D when α is less than 6 degrees. Each induced astigmatic correction was subsequently verified using the wavefront sensor. This also ensured that the cross-cylinder device did not introduce significant amounts of HOAs. Astigmatism was corrected in eyes with values higher than double the estimated SD (0.065 D); that is, higher than 0.13 D. In all subjects, the residual astigmatism after correction was less than 0.07 D. From the measured wavefront aberrations, the associated eye's point-spread function was determined for each subject when defocus C(2,0) was set to zero and for 3 conditions as follows: natural astigmatism, corrected astigmatism, and astigmatism only (with all HOAs removed).

Visual Acuity Measurements

Visual acuity was measured monocularly by presenting tumbling E letters in a computer monitor with 100 candelas/m^2 luminance and placed 8 m from the tested eye. The subject's head was stabilized by a chinrest; the eye looked through an optical bench composed of a Badal optometer to allow subjective adjustment of the best focus and a system including illumination infrared light-emitting diodes, a pellicle beam splitter, and a charge-coupled device video camera to control pupil centration and size. The study was performed under normal pupil conditions. The cross-cylinder device was placed in front of the eyes to correct astigmatism. High-contrast visual acuity (100%) and low-contrast visual acuity (LCVA) (20%) were measured using tumbling E letters with natural and corrected astigmatism using the following steps: (1) The subject looked for the best subjective focus using the Badal optometer starting from a myopic position to reaching the clearest vision of a 0.4 logMAR letter. (2) The letter size was reduced up to the limit of detection. (3) This reference size and 4 other sizes (2 up and 2 down) were randomly presented in 4 orientations (right, left, up, and down). (4) Visual acuity was calculated as the letter size corresponding to 62% of the corrected responses from a psychometric function (4-parameter sigmoidal fit) of correct responses for different sizes.

RESULTS

The study evaluated 54 healthy eyes. The mean age of the subjects was 25 years ± 4 [SD] (range 19 to 35 years). Astigmatism was corrected in 47 eyes. The mean pupil diameter during visual acuity measurements was 6.4 ± 0.8 mm (range 5.0 to 8.0 mm).

Figure 1 shows the logMAR HCVA and LCVA as a function of uncorrected astigmatism and corrected astigmatism. There was a weak correlation between the increases in astigmatism and the deterioration in HCVA ($R^2 = 0.02$); LCVA did not have a correlation

Submitted: June 8, 2013.
Final revision submitted: August 7, 2013.
Accepted: September 13, 2013.

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Supported by the Ministerio de Ciencia e Innovación, Spain (grants FIS2010-14926 and CSD2007-00013), Fundación Séneca, Region de Murcia, Spain (grant 4524/GERM/06), and European Regional Development Fund (EU-FEDER).

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