Effect of Higher Order Aberrations on Contrast Sensitivity Function in Myopic Eyes

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Abstract

Purpose: To evaluate the relation between higher order aberrations (HOAs) and contrast sensitivity function (CSF) in a population with myopia.

Methods: In this case series, HOAs were measured in 70 myopic eyes over a 6-mm pupil. Contrast sensitivity was also measured. From the contrast sensitivity data, the area under the log contrast sensitivity function (AULCSF) was calculated. Pupil diameter was measured under photopic conditions.

Results: Seventy right eyes of 70 myopic subjects with a mean age of 26.6 ± 5.7 years were studied. The mean spherical equivalent and refractive astigmatism were −4.97 ± 1.6 D and 0.93 ± 0.5 D, respectively. AULCSF was significantly but negatively correlated with the cycloplegic spherical equivalent (r² = 0.57, P = 0.02), the root mean square (RMS) of total HOAs (r² = 0.065, P = 0.03), the RMS of fourth-order aberrations (r² = 0.089, P = 0.015), and the RMS of the spherical aberration (r² = 0.037, P = 0.004). AULCSF did not have any significant association with age, photopic pupil diameter, refractive astigmatism, or the RMS of the coma aberration.

Conclusion: Spherical and fourth-order aberrations significantly affect CSF in myopic eyes. However, the effect of myopia on CSF cannot be attributed only to HOAs. Other factors such as neural elements in the visual pathway should be taken into account.

Key Words: contrast sensitivity function, higher order aberrations, myopia

Introduction

Contrast sensitivity, defined as the ability to detect differences in luminance between adjacent areas, is a fundamental feature of vision. Measurement of contrast sensitivity can provide useful information about visual function that may not be obtained by standard visual acuity testing, which determines the overall quality of visual performance only at high contrast. Therefore, it has been proposed that contrast sensitivity should also be tested since it more closely represents visual performance. Optical aberrations such as defocus, astigmatism, and higher order aberrations (HOAs) affect the quality of the retinal image and often cause visual distortions, particularly in contrast sensitivity and mesopic visual acuity. Several studies have demonstrated the deteriorating effect of HOAs, caused by refractive surgeries, on contrast sensitivity function (CSF). However, such reports on normal virgin eyes are very rare, and since customized ablation has recently emerged as a treatment for refractive error, it is important to know exactly how HOAs affect visual functions such as CSF.

In this study, we evaluated the influence of myopia and related HOAs on CSF in normal eyes.
Methods

The participants were randomly selected (simple random sampling) from patients scheduled for refractive surgery. All participants were free from any ocular pathology other than myopia of less than −9.0 D and refractive astigmatism of less than 2.50 D. Best-corrected visual acuity (BCVA) was 20/20 or better in all eyes. Also, patients with a history of any ocular surgery were excluded from the study. Soft and rigid gas-permeable hard contact lenses were discontinued for 2 and 6 weeks, respectively, before the study. To prevent duplication of data, only the right eye of each person was evaluated. Informed consent was obtained from all participants after the nature of the experiment had been explained to them.

The eye examination included a case history, measurements of Snellen BCVA and cycloplegic refractive errors, a slit-lamp examination of the anterior segment, a dilated fundus examination, and measurements of intraocular pressure, horizontal pupil diameters in photopic illumination, CSF, and ocular wavefront aberrations.

The monocular photopic CSF was measured with sine-wave gratings at six spatial frequencies [1, 2, 6, 12, 15, and 18 cycles per degree (cpd)] for day vision simulations using the Metrovision Moniteur Ophtalmologique STATphot program (Metrovision, Pérenchies, France). During the determination of CSF, the chart was viewed from a distance of 20 m with the patient’s full correction in place. After an initial demonstration of the CSF procedure, the contrast threshold was measured for each spatial frequency. All patients were tested in normal room lighting where the reflected luminance of the test pattern at the patient’s facial plane was 500 lux. The area under the log contrast sensitivity function (AULCSF) was calculated according to the method of Applegate et al. The log contrast sensitivity versus log spatial frequency data (corrected for the effects of spectacle-associated minification) were fitted to a third-order polynomial. The fitted function was integrated between the fixed limits of a log spatial frequency of 0 (corresponding to 1 cpd) and of 1.26 (18 cpd), and the resulting value was defined as the AULCSF. By this method, contrast sensitivity data are represented as a single number, making statistical analysis easier. This single quantity was used to find the effects of age, refractive error, and higher order aberrations on CSF.

As the CSF was checked while myopia-correcting spectacles were in place, the minification effect of the glasses had to be taken into account. For example, a patient with myopia of −6.0 D with a 16-mm spectacle vertex distance would experience an approximately 10% decrease in spatial frequency (i.e., increase in cycle width) if instead of glasses, contact lenses were fitted. In the present study, therefore, spatial frequencies were adjusted by correcting the magnification effects caused by moving the refractive correction from the spectacle plane to the corneal plane (Appendix).

After CSF was measured, cycloplegic refraction was determined by using 1 drop of 1% cyclopentolate. Thereafter, when the pupil diameter was greater than 6 mm, aberrometry was performed with a Zywave II aberrometer with Zywave software version 5.2 (Bausch & Lomb, Rochester, NY, USA) in a dark room. This aberrometer was used to calculate the HOAs over a 6-mm pupil in terms of Zernike polynomials up to the fifth order. All Zernike coefficients were converted to the standard form recommended by the Optical Society of America. The analyzed parameters were Zernike coefficients from the third to fifth orders, the root mean square (RMS) of the total number of HOAs from the third to fifth orders, the RMS of the spherical aberration (square root of the sum of the squared coefficients of Z4), the RMS of the coma (square root of the sum of the squared coefficients of Z1, Z3, Z5, and Z7), the RMS of the trefoil (square root of the sum of the squared coefficients of Z3, Z5, Z7, and Z9), and the RMS of the third-, fourth-, and fifth-order aberrations.

Pupil diameter under photopic conditions (270 lux) was measured using a digital camera (E-300; Olympus, Tokyo, Japan). Accommodation was controlled by instructing the participants to fixate on an accommodative target located 4 m away. The photographs were transferred to a computer, and pupil diameter was measured using specialized, non-commercial analysis software. As the pupillary diameter was different at the aberrometry and CSF examinations, the Zernike coefficients were rescaled to the pupil size at which the CSF measurement was done.

Multiple regression analysis was performed to explore the correlation between CSF and several variables based on the square of Pearson’s correlation coefficient (R2). The dependent variable was the AULCSF. Explanatory variables included age, spherical equivalent, photopic pupil diameter, and the RMS of the HOAs. A probability of less than 5% (P < 0.05) was considered statistically significant.

Results

Seventy right eyes of 70 participants (26 men, 44 women) with ages ranging from 18 to 43 years (mean, 26.6 ± 5.7 years) were studied. Mean spherical equivalent and refractive astigmatism were −4.97 ± 1.6 D (range, −1.50 to −8.50 D) and 0.93 ± 0.5 D (range, 0–2.0 D), respectively. The CSF data without correction for refractive error are shown in Fig. 1.

Multiple regression analysis showed that the AULCSF was significantly and negatively correlated with the absolute cycloplegic spherical equivalent (R2 = 0.57, P = 0.02), the RMS of the total number of HOAs (R2 = 0.065, P = 0.03), the RMS of fourth-order aberrations (R2 = 0.089, P = 0.015), and the RMS of spherical aberration (R2 = 0.037, P = 0.004).

Considering the Zernike coefficients individually, we found a significant association only between vertical secondary astigmatism and the AULCSF (R2 = 0.16, P = 0.008). (Figs. 2–6)

The analysis failed to demonstrate a significant association of the AULCSF with age (P = 0.09), photopic pupil...