The effect of corneal edema on visual function

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Corneal edema was produced by atmospheric-induced anoxia and the visual effect was assessed by conventional acuity tests and compared with contrast sensitivity measurements. For the degree of edema which this technique produced, contrast sensitivity was depressed for only high spatial frequencies and could be considered in terms of equivalent defocus. This was not the case for a greater degree of edema which was simulated by a diffuser with a particle size that mimics the diffraction effects from an edematous cornea. Equivalent blur was not applicable, since low spatial frequencies were also affected and the letter and contrast-sensitivity tests gave radically different results. In the light of these findings, the validity of the present letter acuity evaluation of visual function for patients in which intraocular scattering is involved is questioned.

Scattering of light within the eye may occur as a result of several conditions including corneal edema, corneal scarring, cataract, aqueous flare, or any loss of transparency of the ocular media. Corneal edema is the example of intraocular scattering considered in this study and may be due to several causes. Any interference with the mechanism for maintaining corneal deturgescence, such as disruption of the endothelium, or any embarrassment to normal corneal metabolism will result in increased hydration of the cornea.

The purpose of this paper is to investigate the visual loss as a result of scattering due to corneal edema without accompanying changes in topography. Knowledge of the extent of visual loss from this condition should be relevant to our understanding of visual function for conditions involving (1) corneal scattering (corneal edema secondary to flexible contact lens wear, corneal edema secondary to degenerative and dystrophic disease, bullous keratopathy, glaucoma, and cataract extraction) and (2) intraocular scattering (cataract, aqueous flare, retinal edema).

Previous research in this field has been directed at assessing visual function through bovine corneal buttons or diffusing cells at various turbidity levels. With this technique visual effects from epithelial and stromal edema can be separated. Edema of the epithelium is more visually debilitating than edema of the stroma. Visual func-
tion under these conditions has been assessed in a number of ways: minimum separable acuity, letter acuity, contrast letter threshold, and glare sensitivity. Glare sensitivity has been shown to be a more sensitive indicator than letter acuity, which is affected only by relatively large amounts of edema.

The present study extends the contrast threshold assessment into the spatial frequency domain while maintaining a fixed mean luminance. The spatial frequency extent of the contrast sensitivity loss for induced corneal edema and simulated edema may well explain why letter acuity tests are so insensitive for assessing visual function when scattering is involved.

**Apparatus and methods**

Vertical sine-wave gratings were generated on the screen of a BWD 525 oscilloscope (P31 phosphor) by the method of Schade as modified by Robson. The mean luminance was set at 80 cd. per square meter; contrast modulation which occurred about this luminance was adjusted with an 80 position-switched logarithmic attenuator connected to a digital voltmeter. The oscilloscope screen was masked down to a 10 by 8 cm. rectangular aperture. A 100 by 75 cm. white surround screen was illuminated to the same luminance. Considerable care was taken to ensure even and matched surround screen and room lighting. A central fixation point was provided to ensure stable accommodation. The oscilloscope's contrast linearity and frequency response were measured with a PIN photodiode, the results from which are displayed in Fig. 1. The contrast testing was designed to work within the linear contrast region and the flat frequency response region of these respective curves. The viewing distance was changed from 57 cm. for low-to-medium spatial frequencies (0.3 to 3 c. per degree) to 570 cm. for higher spatial frequencies. The field size therefore varied from 10° by 8° to 1° by 0.8°, ensuring that at least three cycles were present at the lowest spatial frequency.

Corneal edema was produced by passing 100 per cent pure, dry nitrogen gas through a tightly fitting rubber goggle (right eye only) which was fitted with a correcting lens (anetropia and testing distance correction). A small positive pressure was maintained within the goggle and the flow rate was decreased to a minimum to avoid direct corneal drying. Corneal thickness was measured with a modified Haag-Streit pachometer attached to a Nikon photo-slit lamp. Care was taken to ensure perpendicular alignment of the slit-lamp illumination system with the anterior corneal surface during the measurements. Although the different contributions of the epithelium and stroma were not measured, the edema-inducing technique and the magnitude of the letter acuity effects strongly suggest that in the light of previous work, the edema was mainly epithelial. Corneal topography was measured before and after application of the edema-producing conditions with an...
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Fig. 2. The time course of corneal thickness change from atmospheric-induced anoxia is plotted in the lower part of the figure. The thickness measurements were taken through the goggle and the form of this response was found to be reproducible. The time scale refers to time from commencement of nitrogen flow. In the upper part of the figure computer plots from the autocollimating photokeratoscope before and after edema production are displayed. There is no significant curvature change over the central optical region as a result of edema.

autocollimating photokeratoscope which, following computer analysis of the data obtained from the photokeratograms, gave a three-dimensional plot along four meridians of the deviation of the corneal shape from the best fitting reference sphere. Corneal thickness and corneal topography were monitored for a week before the experiment and found to be stable. All tests and measurements were restricted to the right eye of Subject R. F. H. So that detailed results could be obtained, only one subject was used for the contrast sensitivity tests. The major conclusions were however rechecked for this subject on subsequent occasions.

Letter acuity was measured on a standard Snellen chart and also Landolt C (approximately 100 per cent contrast) frequency-of-seeing data were probit-analyzed to obtain a more accurate 50 per cent threshold letter acuity before and after edema. Each letter size was presented 32 times.

All measurements except for corneal topography were performed before and after edema through the goggle to ensure no recovery effects. All acuity tests had a fixed background luminance of 80 cd. per square meter. Natural pupils were used and monitored photographically at half-hour intervals for the duration of corneal anoxia.

Results

The time course of the corneal thickness change from 100 per cent nitrogen together with computer plots of corneal topography before and after edema are shown in Fig. 2. The corneal thickness measurements were made through the goggle in order to
exclude recovery effects. Each point represents the mean of six pachometer settings; the average standard error of the mean was equivalent to a 0.4 per cent thickness change. There was little or no effect for the first hour; thereafter thickness increased until a plateau was reached after approximately 3½ hours. The time course of this thickness change was found to be a reproducible feature and it is consistent with previously published work. The value of the peak thickness change was variable from day to day. The range of this variation was from 4 to 6 per cent for the subject used.

Computer plots from the autocollimating photokeratoscope, which depicts corneal topography before and after edema (included in Fig. 2), show that there was some peripheral steeping after edema and there was not a significant curvature change over the central 3 mm. zone of the cornea. This central zone was spherical and was fitted to approximately identical reference spheres before and after edema. Conventional keratometry also showed no topography change before and after edema. The corneal swelling from “atmospheric anoxia” was thus evenly distributed, enabling any turbidity-induced acuity effect to be measured unassociated with curvature changes.

The photokeratoscopy results together with careful slit-lamp examination also ensured that small epithelial surface irregularities were not produced as a side effect of the edema-inducing technique (i.e., from direct epithelial drying).

Fig. 3 shows Landolt C letter acuity (50 per cent threshold) effects from corneal edema (6% thickness change). The probit values are plotted against the logarithm of the angular size. The 50 per cent threshold acuity changed from 6/3.8 to 6/7.2; for the clinical Snellen letter chart of the same background luminance, acuity changed from 6/5 to 6/6.

The contrast sensitivity results before and after edema are displayed in Fig. 4. Contrast sensitivity, which is the reciprocal of the contrast threshold, is plotted on a log scale against spatial frequency (log scale), which is the reciprocal of size in cycles per degree of visual angle. Contrast sensitivity was set for different spatial frequency sine-
wave gratings of fixed mean luminance. Each point represents the mean of five readings; the average standard error of the mean was equal to half the symbol size. The upper curve represents the ratio of normal/edema contrast sensitivities and normal/recovery contrast sensitivities. This is plotted as the log threshold elevation (log ratio of contrast threshold). The probability that this contrast threshold elevation is not significant is indicated for a 5 c. per degree grating.

The edema-induced depression (6 per cent thickness change) in contrast sensitivity involves only the high spatial frequency region of the contrast function, the peak and low frequency regions are unaffected. The contrast sensitivity curve which was measured 3½ hours later is seen to have fully recovered. The time course of the contrast sensitivity abnormality is seen in Fig. 5. Three representative spatial frequencies were tested over the time course of thickness change which have been superimposed over the contrast results for comparison. Only the high spatial frequency grating was affected; the time course of this effect parallels the thickness change time course.

Figs. 6 and 7 display acuity effects through a diffuser (particle size 19 µ and average interparticle distance 30 µ) positioned close to the cornea for contrast sensitivity (Fig. 6) and Landolt C acuity (Fig. 7). The normal and equivalent blur (defined as dioptric blur producing the same high frequency contrast sensitivity loss) results for both tests have been corrected for equal light transmission with a 0.3 N.D. filter. Visual function through the diffuser as assessed by the contrast sensitivity function is worse than the equivalent blur, yet when assessed by the letter acuity test, it is better than the equivalent blur.

Discussion

The corneal thickness change which occurs from atmospheric-induced anoxia has been previously documented and there is substantial agreement between the present findings and those previously reported. No effect was detected during the first hour, thereafter the cornea swells reaching a plateau at about 2½ hours. The form of this thickness change was found to be reproducible on a number of occasions; however, the corneal thickness change corresponding to the peak was variable from day to day. Over a 1 week period this value varied from 4 to 6 per cent thickness change. Corneal topography changes resulting from the induced edema were slight and confined to the peripheral corneal re-
region. Significant curvature changes in the central cornea were not measurable with either photokeratoscopy or conventional keratometry. Photokeratoscopy and slit-lamp examination revealed no surface epithelial irregularities; thus the corneal swelling produced by this technique was evenly distributed across the central region of the cornea and the visual loss which resulted was due to increased scattering within the tissue and not to an epithelial reaction due to the dry nitrogen.

Snellen acuity before and after 3½ hours corneal edema changed from 6/5 to 6/6. Landolt C 50 per cent acuity thresholds changed from 6/3.8 before edema to 6/7.2 after edema. Letter acuity tests are questionable measures of general visual performance, since they are spatially complex and represent only one contrast level (approximately 100 per cent). The results from these tests are specific to the reading situation and only qualitative indicators of general visual performance. The contrast sensitivity function has potential as a general test of visual function because it measures the important parameter of contrast sensitivity over a part of the visible spatial frequency range, maintaining constant light adaptation for spatially simple targets. This test supplies a quantitative description of visual loss in terms of contrast sensitivity. The normal contrast sensitivity function has a peak around 3 c. per degree, a low frequency decline in contrast sensitivity of approximately unity slope, and a high frequency decline which when extrapolated to the abscissa, results in the cut-off spatial frequency acuity. Corneal edema (probably mainly epithelial in nature) produced by 3½ hours of atmospheric-induced anoxia resulted in depressed contrast sensitivity for high spatial frequencies, but the effects on the peak and the low spatial frequency regions of the contrast function were not measurable. The high frequency contrast loss is seen to be a significant effect (upper curve of Fig. 4) with recovery complete in 3½ hours. The edema effect is frequency dependent: the higher the frequency the greater the visual loss. Although changes in corneal curvature and surface irregularities have been ruled out as contributing to the visual loss, it could be argued that these contrast abnormalities are the result of pupil changes or reduced light transmis-
sion induced by the edema and not the scattering effect per se. Pupil size was photographically monitored every half hour for 3 1/2 hours of atmospheric-induced anoxia and did not vary significantly.

Any light transmission loss would have been slight, since there was no obvious neutral density effect when the edematous and nonedematous eyes were compared viewing an unpatterned field. Any slight light transmission loss would have had little or no effect on contrast sensitivity for high-spatial-frequency gratings for the mean luminance used.11

The spatial frequency extent of the contrast loss is substantiated by the results of a second experiment (Fig. 5) in which contrast sensitivity for representative spatial frequencies was measured during the time course of edema production. The low and peak spatial frequencies were not affected by this degree of corneal edema, whereas the high spatial frequency effect is seen to parallel the corneal thickness change. In the first hour there was no detectable thickness change or contrast sensitivity effect; from the first to the third hour the cornea swelled and contrast sensitivity was depressed; and at about 3 to 3 1/2 hours a plateau for both curves was reached. These results support the proposition that contrast sensitivity is affected for only high spatial frequencies for edema of this magnitude. This edema-induced contrast sensitivity loss can be thought of as equivalent to dioptric defocus, since small degrees of simple blurring affect the contrast sensitivity function in a similar way. It is for this reason that acuity measures (such as grating resolution at 100 per cent contrast) would be valid determinators of the type of visual loss associated with edema of this magnitude, although of course they would be less sensitive, depending upon the slope of the high frequency fall-off in sensitivity. For example, in Fig. 4 contrast sensitivity changed by 70 per cent for a 35 c. per degree grating, yet the cut-off spatial frequency acuity changed only 27 per cent.

Would one expect greater degrees of edema to affect the peak and low spatial frequency limb? A greater degree of edema was simulated by means of a diffuser (positioned close to the cornea) with a particle size that mimics diffraction effects from an edematous cornea.12 The light transmission loss from the diffuser was measured in a spectrophotometer and adjusted accordingly, so that all conditions were compared for the same mean luminance. Contrast sensitivity was depressed for all spatial frequencies by this diffuser (Fig. 6). The effect was compared with the equivalent defocus (defined as the defocus which produced the same high frequency loss); however, it was found that this defocus (+1.25 D) did not have a measurable effect upon the low spatial frequencies. With small degrees of
edema, the scattering effect can be considered as equivalent to defocus whereas with greater amounts of scattering (edema) the defocus equivalent is not applicable.

This latter point implies that acuity (high frequency) based tests could give a misleading picture of the extent of the visual loss when greater degrees of scattering are involved. Indeed an interesting reversal occurs when the equivalent defocus and the diffuser are compared for letter acuity. Visual function as assessed by the letter acuity test is much better for the diffuser (6/7.3) than for the equivalent defocus (6/15.6). The opposite conclusion is arrived at when visual function is assessed by the contrast sensitivity test. The final decision can be made by viewing through each of these filters and evaluating them in terms of their general visual effect. When this is done there is no difficulty, for the masking effects introduced by the diffuser are far more visually debilitating than the blurred edge effects introduced by the equivalent defocus. This effect may be paralleled in the driving situation. It is not unusual in the clinical environment to examine patients who have been driving successfully with large degrees of “defocus acuity loss,” yet we know how visually destructive atmospheric scatter (fog) can be for such a task.

These results add indirect evidence for the importance of the low spatial frequencies to perception and for the inappropriateness of letter or other acuity tests as general visual performance determinators when contrast sensitivity is depressed for low spatial frequencies. This latter point could have a significant bearing on our present visual loss assessment from intraocular scattering conditions of which there are many. If this diffuser validly simulates the effect of a greater degree of intraocular scattering, then the visual performance of these patients is being grossly overestimated with our present letters on “acuity” tests.

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REFERENCES
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