Effect of Ultraviolet Radiation on Cataract Formation


Abstract  To investigate the relation of ultraviolet radiation and cataract formation, we undertook an epidemiologic survey of 838 watermen (mean age, 53 years) who worked on Chesapeake Bay. The annual ocular exposure was calculated from the age of 16 for each waterman by combining a detailed occupational history with laboratory and field measurements of sun exposure. Cataracts were graded by ophthalmologic examination for both type and severity.

Some degree of cortical cataract was found in 111 of the watermen (13 percent), and some degree of nuclear cataract in 229 (27 percent). Logistic regression analysis showed that high cumulative levels of ultraviolet B exposure significantly increased the risk of cortical cataract (regression coefficient, 0.70; P = 0.04). A doubling of cumulative exposure increased the risk of cortical cataract by a factor of 1.60 (95 percent confidence interval, 1.01 to 2.64). Those whose annual average exposure was in the upper quartile had a risk increased by 3.30 (confidence interval, 0.90 to 9.97) as compared with those in the lowest quartile. Analysis using a serially additive expected-dose model showed that watermen with cortical lens opacities had a 21 percent higher average annual exposure to ultraviolet B (t-test, 2.23; P = 0.03). No association was found between nuclear cataracts and ultraviolet B exposure or between cataracts and ultraviolet A exposure.

We conclude that there is an association between exposure to ultraviolet B radiation and cataract formation, which supports the need for ocular protection from ultraviolet B. (N Engl J Med 1988;319:1429-33.)

There are photobiologic, biochemical, and experimental reasons to suppose that exposure to sunlight, specifically ultraviolet radiation, may be a cause of senile cataracts1-5 although firm epidemiologic evidence has been lacking. Cataracts occur more commonly in tropical or sunny areas than in more temperate regions.6-9 Studies in Australian aborigines have shown a dose-response relation between the prevalence of cataracts and levels of ultraviolet B radiation.10,11 In the United States, data from the National Health and Nutrition Examination Survey have suggested that people with higher exposures to sunlight or ultraviolet-radiation levels have an increased risk of cataract, specifically cortical cataract.8,12,13

However, these epidemiologic studies suffer from a lack of precision both in the definition of cataract and in the quantification of exposure to ultraviolet radiation. There are three major anatomical and morphologic types of senile cataract, each of which may have different risk factors: nuclear cataract, which occurs in the nucleus of the lens; cortical cataract, which occurs in the surrounding cortex; and posterior subcapsular cataract, which occurs beneath the posterior capsule.

If ultraviolet radiation is a cause of cataracts, there would be major public health implications. More than 1 million cataract operations are performed each year in the United States.14 Worldwide, more than 17 million people are blinded by cataracts.15 Furthermore, there is evidence that we will face significantly higher levels of ultraviolet B as a result of the progressive reduction in the ozone layer that filters ultraviolet B in the stratosphere.20 Therefore, we undertook an epidemiologic study to assess the ultraviolet-radiation exposure among watermen of the Chesapeake Bay and its relation to the two major types of senile cataract.

Methods

Study Population

Men 30 years of age or older residing in either Somerset County (excluding Princess Anne) or lower Dorchester County, Maryland, and holding at least one type of waterman's license within the past 10 years were eligible for this study. A licensing list was obtained from the Maryland Department of Natural Resources, which maintains computerized records back to 1974. The list was updated and...
Examination

The watermen were examined at a convenient central site in each town. A pretested questionnaire was administered by a trained interviewer without knowledge of the results of subjects' ophthalmologic examinations. The questions addressed demographic and background characteristics, including birth date, education, residential history, and characteristics of freckling and sunburning; medical history, including use of phototoxic drugs, history of diabetes or hypertension, and use of steroids, aspirin, antihypertensive and cardiac medication, and tobacco; and sun-exposure history, including a detailed occupational history covering each year of life from the age of 16 years, in which daily exposure data were recorded on a monthly basis, and a similar history for leisure activities. Both histories included information about the number of hours spent outside, use of hats, use of glasses, and any history of arc welding.

Each subject had an ocular examination that included slit-lamp examination after pupillary dilation. The examining ophthalmologist was unaware of subjects' occupational and exposure history and visual-acuity status. Lens changes were graded according to anatomical location and severity.

Cortical opacities were defined as opacities in the external one third of the lens sufficiently dense to be seen on retroluminstration. These were graded for severity according to the estimated area of the lens affected by spores. The area of the opacities was expressed as the cumulative number of one-eighth wedges of the retroluminated cataract.

Nuclear opacities were defined as opacities seen in the optical section of the inner two thirds of the lens. These were graded according to the expected effect on visual acuity as follows: grade 0, no opacity; grade 1, some opacity, but consistent with vision of 20/20; grade 2, opacity consistent with vision between 20/25 and 20/30; grade 3, opacity consistent with vision between 20/40 and 20/100; and grade 4, opacity consistent with vision of 20/200 or less. These grades were defined according to standard photographs, and the grading was made without knowledge of subjects' actual visual acuity.

In the presence of a posterior subcapsular cataract, the overall height and width of the opacity seen on retroluminstration were measured with use of the slit-lamp graticule. Any lens that had been operated on, even if lens remnants were present, was regarded as aphakic. There were 18 subjects with aphakia. The operating ophthalmologist was contacted in each case, and the preoperative diagnosis of the type of cataract was obtained for 17 of the 18.

Analyses were performed for each type of opacity with use of the grade for the most severely affected eye. Two men with congenital cataracts and 12 eyes with traumatic opacities were excluded.

Data Analysis

Data were analyzed with use of an SAS standard statistical package to calculate Mantel–Haenszel summary odds ratios. Logistic regression models were used to analyze the independent contribution of ultraviolet B and ultraviolet A to the risk of opacity. Analyses were done on those with established lens opacities of grade 2 or worse.

A serially additive expected-dose model was used to explore the relation between ultraviolet B exposure and lens opacities. This method involves calculating the expected yearly exposure to ultraviolet B for each subject with cataracts on the basis of the combined data from all controls without cataracts of the same age group (matched within three years of age). The actual observed cumulative dose for each subject was then compared with the expected dose, and the paired t-test was used to test the difference.

Calculation of Ocular Exposure to Ultraviolet A and Ultraviolet B

The ocular exposure to ultraviolet B in each subject was determined by combining field-derived and laboratory-derived data and published data on levels of ambient ultraviolet B with personal exposure histories obtained in interviews. Field investigations determined the average proportion of exposure to ambient ultraviolet B that reached the eyes of subjects not wearing spectacles or sunglasses. These data were collected for work over water and over land, for summer and winter, and for hat use. Personal ocular exposures were corrected for the attenuation due to eyewear by combining each subject's history of use of eyewear with laboratory measurements of the attenuation of ultraviolet B due to typical spectacles with glass or plastic lenses, as appropriate.

These data permitted the calculation of the yearly ocular exposure to ultraviolet B in each subject for each year of life beyond the age of 15. The annual exposure was expressed as a proportion of Maryland sun years; 1 Maryland sun year is equal to the total ambient ultraviolet radiation at sea level in Maryland over a one-year period. Ambient ultraviolet radiation was defined as the irradiance of a horizontal surface under an unobstructed sky. As a comparison, Scoot and coworkers determined that the annual ambient ultraviolet B in Philadelphia was approximately 2500 minimal erythemal doses, which is approximately equivalent to 95 J per square centimeter.

To estimate the ocular exposure to ultraviolet A, a similar procedure was used. Ambient ultraviolet A levels were estimated by convoluting the spectral distribution of sunlight as a function of the month, the hour of the day, and the geographic location with two ultraviolet A response spectrums designated as ultraviolet A1 (wavelength, 320 to 340 nm) and ultraviolet A2 (wavelength, 340 to 400 nm). As expected, the exposures determined for ultraviolet A were highly correlated with those for ultraviolet B. The correlation coefficient for ultraviolet A1 as compared with ultraviolet B was 0.99; the correlation coefficient for ultraviolet A2 as compared with ultraviolet B was 0.95.

RESULTS

Of the 838 watermen examined, 204 (24 percent) were between 30 and 39 years of age, and 140 (17 percent) were over the age of 70. The oldest was 94, and the mean age was 53.0 years. Twenty-four watermen (3 percent) were black.

Figure 1. Distribution of the Frequency of Average Annual Ocular Exposure to Ultraviolet B among 838 Maryland Watermen. Values are expressed as a proportion of total ambient ultraviolet B (equal to 1 Maryland sun year).
A. Cortical Opacity

Grade

I or worse

2 or worse

3 or worse

4

B. Nuclear Opacity

Figure 2. Age-Specific Prevalence of Cortical (Panel A) and Nuclear (Panel B) Opacities, According to Severity in the More Severely Affected Eye among 838 Maryland Watermen.

The average annual ocular exposure ranged from 0.001 to 0.074 Maryland sun year, with a median of 0.022 Maryland sun year (Fig. 1). The maximal possible annual ocular exposure in Maryland is 0.09 Maryland sun year. To achieve this exposure, one would have to work on the water all day, every day of the year, and not wear a hat or glasses.

Distribution of Lens Opacities and Cataracts

Overall, 111 watermen (13 percent) had some cortical lens opacity, and 229 (27 percent) had some nuclear opacity, including those who had undergone cataract surgery. There was a progressive increase in the prevalence and severity of cortical and nuclear opacities with age (Fig. 2). Only 14 watermen were found to have posterior subcapsular cataracts, including 7 who had undergone cataract surgery for this condition. These numbers were too few to provide firm age-specific prevalence rates, and no further analyses are presented on this type of cataract.

Ultraviolet B Exposure and Cataracts

To identify potential confounding factors, age-adjusted bivariate analyses were performed (Table 1). Subsequent logistic regression analysis adjusting for age revealed a statistically significant association between total cumulative ultraviolet B exposure and cortical opacities (regression coefficient, 0.70; 95 percent confidence interval, 0.01 to 1.40). For a given age, a doubling of cumulative ultraviolet B exposure was associated with a 1.6-fold (95 percent confidence interval, 1.01 to 2.64) increased risk of cortical cataract. No other variable was associated with cortical opacities in this model. No increased risk was apparent for nuclear opacities, even after an adjustment for age, susceptibility to sunburn, and a history of hypertension (regression coefficient, −0.01; 95 percent confidence interval, −0.32 to 0.31). The risk of cortical cataract increased markedly with increasing annual average exposure. The odds ratio for exposure in the highest quartile was 3.30 (95 percent confidence interval, 0.90 to 9.97; Table 2), as compared with the lowest quartile.

The ultraviolet B exposure in the 34 watermen with cortical opacities was significantly higher than the expected exposure calculated with use of the serially additive expected-dose model (t-test, 2.23; P < 0.03; Fig. 3). It is clear that in those with cortical opacities, excess exposure occurs in every year of life after age 15, suggesting that the damage is cumulative. On average, subjects with cortical cataracts had a 21 percent higher exposure to ultraviolet B. There is no evidence that excess exposure occurs at a particular susceptible period of life or has an obligatory latency period.

Ultraviolet A Exposure and Cataracts

Parallel analyses were performed for two action spectra that included ultraviolet A from 320 to 340 nm and from 340 to 400 nm. These analyses did not show a statistically significant relation between exposure and cataract formation.

Table 1. Age-Adjusted Bivariate Analysis of Risk Factors Associated with Lens Opacities in 832 Watermen.

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>No. of Subjects</th>
<th>Age-Adjusted Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Subjects with Cortical Cataracts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(N = 111)</td>
</tr>
<tr>
<td>Cardiac medication or diuretic</td>
<td>163</td>
<td>1.5 (0.9–2.4)</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>286</td>
<td>0.9 (0.6–1.4)</td>
</tr>
<tr>
<td>Smoking</td>
<td>660</td>
<td>1.3 (0.8–2.3)</td>
</tr>
<tr>
<td>Freckling</td>
<td>402</td>
<td>0.9 (0.5–1.4)</td>
</tr>
<tr>
<td>Steroid use</td>
<td>33</td>
<td>0.5 (0.1–2.1)</td>
</tr>
<tr>
<td>Susceptibility to sunburn</td>
<td>279</td>
<td>1.1 (0.7–1.8)</td>
</tr>
<tr>
<td>Aspirin use</td>
<td>301</td>
<td>1.1 (0.7–1.8)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>62</td>
<td>1.3 (0.6–2.6)</td>
</tr>
<tr>
<td>&gt;8 Yr of education</td>
<td>502</td>
<td>1.3 (0.8–2.1)</td>
</tr>
<tr>
<td>Arc welding</td>
<td>227</td>
<td>1.0 (0.5–1.8)</td>
</tr>
<tr>
<td>Blue eyes</td>
<td>480</td>
<td>0.6 (0.4–1.0)</td>
</tr>
<tr>
<td>Actinic elastosis</td>
<td>422</td>
<td>0.8 (0.5–1.3)</td>
</tr>
<tr>
<td>Pterygium</td>
<td>140</td>
<td>0.8 (0.5–1.4)</td>
</tr>
<tr>
<td>Pinguecula</td>
<td>640</td>
<td>0.8 (0.4–1.3)</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>15</td>
<td>0.5 (0.1–1.9)</td>
</tr>
</tbody>
</table>

*CI denotes confidence interval.

The number of watermen with this risk factor for whom data on cataracts are available. P < 0.05, by chi-square test.
sure to either ultraviolet A1 or ultraviolet A2 and cortical or nuclear opacities, either in a logistic regression model or in the serially additive expected-dose model. However, a nonsignificant relation was found between ultraviolet A1 (wavelength, 320 to 340 nm) and cortical cataracts that was comparable to that observed with ultraviolet B (odds ratio for exposure in the highest quartile as compared with the lowest quartile, 1.95; 95 percent confidence interval, 0.41 to 9.35).

**Discussion**

In this study of Chesapeake Bay watermen, we found a clear association between the degree of ultraviolet B exposure and the risk of cortical cataracts. The subjects with cortical cataracts had a greater exposure to ultraviolet B radiation from the age of 16 on than did those without cortical cataracts. The risk of cortical cataracts was increased 3.3-fold in those who had ultraviolet B exposure in the highest quartile, as compared with those with exposure in the lowest quartile. No association was found between ultraviolet B exposure and nuclear opacities or between ultraviolet A exposure and either type of opacity.

The watermen of Chesapeake Bay were selected for study because they form a stable occupational group with a wide range of sun exposure. Although this was a cross-sectional study, efforts were made to avoid selection bias by including all eligible men, including former professional watermen. There is a perceived benefit to paying the nominal fee for a waterman's license even if professional activities have ceased; only five watermen in these communities who were known to be inactive were not included in our licensing list from 1974. Selection bias would have an effect if watermen without lens opacities but with a high ultraviolet exposure selectively left the study communities or if those who left had lens opacities and low exposures. In the age groups studied, few ever move away from these stable communities, and decisions to leave would be unlikely to be related to ultraviolet exposure. Thus, we believe that selection bias was probably not an important factor. In fact, the watermen are an ideal group to study, because it is possible to determine their work habits accurately and therefore their occupational exposure to ultraviolet radiation over their entire work-lives. Because of individual variation in factors such as work history, habits, and hat and spectacle use, their personal exposures to ultraviolet radiation encompassed a broad range. The ocular-exposure model integrated these data with the history of occupational exposure in each waterman, giving an assessment of individual ocular exposure to ultraviolet B with greater precision than has previously been possible.

Although we found a strong association between ultraviolet B exposure and cortical cataracts, we did not find nuclear cataracts to be associated with ultraviolet B exposure. This does not necessarily mean that ultraviolet B exposure plays no part in the induction of nuclear cataracts, but if an association exists, it would seem to be much weaker than that for cortical cataracts. Much of the biochemical literature on ultraviolet-radiation exposure and cataracts has focused on the changes that occur in the nuclear pigmenta-
tions. Furthermore, field reports have often reported the occurrence of mature or advanced cataracts that include nuclear changes. Taken together, these reports may have fostered the notion that an association would be expected between ultraviolet B and nuclear cataracts rather than cortical cataracts. However, the biochemical evidence for ultraviolet-induced changes in the proteins of the cortex seems to be at least as compelling as that for nuclear proteins. The data from studies in animals all point toward ultraviolet B as a cause of cortical changes rather than nuclear changes. Field reports that have distinguished cataracts according to type have suggested an association between ambient ultraviolet B exposure and cortical cataracts but not nuclear cataracts—a finding that is consistent with ours.

Ultraviolet radiation is subdivided into three bands: A (wavelength, 400 to 320 nm), B (wavelength, 320 to 290 nm), and C (wavelength, 290 to 100 nm). Ultraviolet A induces suntanning, whereas ultraviolet B causes sunburn, blistering, and skin cancer. Ultraviolet C does not naturally penetrate to the earth's...
surface. Although the lens absorbs almost all ultraviolet B radiation, it transmits more ultraviolet A.1 Experimentally, the lens has been shown to be most susceptible to damage from radiation in the ultraviolet B band.2,3 Thus, it is not surprising that a differential effect on the lens was seen between exposure to ultraviolet A and ultraviolet B.

However, ultraviolet B exposure accounts only partially for the occurrence of cortical cataracts. The etiologic process of cataracts is almost certainly multifactorial, although none of the other potential risk factors that we examined were associated with lens opacities. The prevalence rates for nuclear opacity were somewhat lower in subjects reporting a history of hypertension. However, because of the large number who reported uncertainty about the use of antihypertensive medication and because blood pressure was not actually measured, this finding should be interpreted with caution. In contrast to reports suggesting a protective effect of aspirin on cataract prevention, we found no evidence that aspirin use, duration of use, or dose had any effect on opacities.24-26

On the basis of these observations, it would seem prudent to protect the eyes from unnecessary exposure to ultraviolet B. The amount of ambient ultraviolet B varies markedly during the day (it is highest in summer between 10 a.m. and 2 p.m.).29 The periods of high levels of ultraviolet B are usually well recognized, for this is the time when sunburn is most likely to occur. Ocular exposure to ultraviolet B can be reduced by half by wearing a hat with a brim, and the wearing of ordinary glasses with plastic lenses may reduce it to about 5 percent.25,26 Thus, to minimize ocular exposure to ultraviolet B, people should be advised to wear a hat with a brim and close-fitting sunglasses with ultraviolet B-absorbing lenses at times of maximal exposure to sunlight.

We are indebted to the many people who assisted with this undertaking: to the staff of the Department of Natural Resources, Dr. Lorraine Cameron, and those who assisted with field work; to Dr. Ben Vitas, Paula Prestia, Maureen Mulcahy, David Emmett, John Lorraine Cameron, and those who assisted with field work; to Dr. Scrimgeour, Colin Phoon, and Charles Swift; to the members of the NIOSH publication no. 77-130.)


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