Sunlight Exposure and Risk of Lens Opacities in a Population-Based Study

The Salisbury Eye Evaluation Project

Sheila K. West, PhD; Donald D. Duncan, PhD; Beatriz Muñoz, MSc; Gary S. Rubin, PhD; Linda P. Fried, MD, MPH; Karen Bandeen-Roche, PhD; Oliver D. Schein, MD, MPH

Context.—Exposure to UV-B radiation in sunlight has been shown to increase the risk of cataract formation in high-risk occupational groups, but risk to the population has not been quantified.

Objectives.—To determine the ocular exposure to UV-B radiation in sunlight for a population of older persons and to determine the association between UV-B and lens opacities.

Design.—The Salisbury Eye Evaluation project, a population-based cohort of older adults.

Setting.—Salisbury, Md.

Participants.—A total of 2520 community-dwelling 65-year-old to 84-year-old adults in Salisbury, Md, from 1993 to 1995, of whom 26.4% were African Americans.

Main Outcome Measure.—Association of photographically documented cortical opacity 3/16 or greater in at least 1 eye with ocular UV-B exposure, reported in Maryland sun-years of exposure.

Results.—The odds of cortical opacity increased with increasing ocular exposure to UV-B (odds ratio [OR], 1.10; 95% confidence interval [CI], 1.02-1.20). The relationship was similar for women (OR, 1.14; 95% CI, 1.00-1.30) and for African Americans (OR, 1.18; 95% CI, 1.04-1.33). Analyses of the ocular dose by each age group after the age of 30 years showed no vulnerable age group, suggesting damage is based on cumulative exposure.

Conclusions.—Although this population of older Americans has relatively low ocular exposure to UV-B in sunlight, there is still an association between ocular exposure and increasing odds of cortical opacity. Our study found an association among African Americans, which, to our knowledge, has not been reported previously. All sex and racial groups would benefit from simple methods to avoid ocular sun exposure.

In particular, several epidemiological studies have been carried out on the relationship between risk of cataract and of sun exposure, especially UV-B exposure. In general, the ecological studies are suggestive of an association between cataract and UV-B exposure, using crude approximations of exposure and various cataract assessment techniques. Three case-control studies found no association of cataract and proxy measures of sun exposures. Two of the studies used nonstandardized assessment of cataract status, and one used insensitive measures of ocular exposure to UV-B. A detailed assessment of ocular exposure to UV-B was carried out in the Chesapeake Bay Waterman study, where increases in average annual ocular exposure were associated with increasing risk of cortical opacity. In this highly exposed group of predominantly white males, the evidence linking cortical opacities to sunlight exposure was the strongest to date.

Despite advances in surgical procedures and targeted programs, cataract remains the leading cause of visual loss worldwide. In the United States, cataract surgery is responsible for 12% of the Medicare budget, or $3.4 billion annually in 1991. Although cataract surgery rates have increased, there are still underserved minority populations where cataract remains an important cause of visual impairment (data available from authors). As the population ages, both in the United States and globally, cataract surgery and loss of vision from cataract will become an even more pressing issue for the eye care community.

Considerable effort to elucidate risk factors for cataract has been undertaken in hopes that simple, preventive strategies may be implemented to avoid or delay the progression of lens opacification.
of exposure with the risk of cortical opacity separately for women and African Americans. In previous publications, we have described the methods and results of our ocular exposure models.17-18 In this article, we describe the association of UV-B with lens opacities.

METHODS

Population

The SEE project is a population-based, longitudinal study of the impact of visual impairment and age-related eye diseases on functional status in older, community-dwelling adults.20 To achieve the aims of this project, a random sample of residents of Salisbury, Md, aged 65 to 84 years was recruited for a home interview and an examination at the SEE clinic, which included lens photography and administration of a questionnaire about sun exposure during leisure and work times over the lifetime of the participant since the age of 30 years. The sample was selected from the Health Care Financing Administration Medicare database, which is reported to include 98% of persons 65 years or older.21 The sample included a 100% sample of the African American population, a 56% sample of whites aged 65 to 74 years, and a 62% sample of whites aged 75 to 84 years. The older age group was oversampled in anticipation of a higher refusal rate among older ages. We included all African Americans aged 65 to 74 years to have sufficient numbers for race-specific analyses. Exclusion criteria included those who were institutionalized, or completely house bound, and those who scored less than 18 on the Mini-Mental State Examination.22 Written, informed consent was obtained at the home interview in accordance with the tenets of the Declaration of Helsinki. Details on the population and recruitment are described elsewhere.21 In summary, of the original sample, 73% participated in the home interview and 65% participated in both the interview and the clinical examination.

Permission was also sought to administer a 12-question screener questionnaire of both the refusals and the participants in order to investigate the comparability between those for whom data were available and those who refused. Of the 1301 refusals to the clinic examination, 10% were recruited for the screener and those who did not answer the screener.22 The screener included the following question related to sun exposure: “For the job you held longest in your life, did you spend more than 2 hours outside during daylight in the summer months?” Another question asked respondents to self-rate their vision status on a scale of 1 to 10, with 10 being excellent. There was no difference in participation rates by race; participation rates declined with age from 68% in the age group 65 to 69 years to 55% in the age group 80 to 84 years. There was no difference between the refusals and the participants in the proportion who reported being outside in the summer months in the job held longest in their lifetime. Among participants, 41% reported being outside more than 2 hours per day, compared with 40% among refusals. There was also no difference in the sex- and age-adjusted proportion rating their vision as 6 or better; 82.9% were 6 or better among participants compared with 84.0% among refusals. These data provide some assurances that the sample of 2520 participants did not seem to be biased on either sun exposure or self-reported vision status.

Lens Opacity Assessment

At the examination center, each participant’s eyes were dilated and lens photographs were taken using standardized protocols previously described.15 Photographs were graded for the type and severity of opacity using the Wilmer grading scheme.23 Nuclear opacification was graded against a standard photograph for the integer grade, with deciliated interpolation between the standards.24 Cortical opacification was graded by estimating the amount of pupillary area obscured, in 1/16th sectors.25 Posterior subcapsular (PSC) opacities were graded as present or absent. All grading was done for each eye independently by 2 trained graders masked to each other’s grade and the grade of the fellow eye. Differences greater than 0.3 in nuclear, 1/16th in cortical, and present or absent in PSC were openly adjudicated with a third grader. Interobserver variation was monitored over the course of the study by the periodic circulation of 53 photographs. The interobserver agreement at baseline was \( \kappa = 0.92 \) (95% confidence interval [CI], 0.85-0.99) for nuclear and \( \kappa = 0.95 \) (95% CI, 0.91-1.0) for cortical. The average \( \kappa \) value for agreement over time was 0.83 for nuclear and 0.81 for cortical.15

Nuclear opacity was defined as present if at least 1 eye had a grade of 2.0 or higher. Cortical opacity was defined as present if at least 1 eye had a grade of 3/16 or higher. Bilateral surgery occurred in 245 participants and the type opacity that was obtained from the surgeon’s records in 185 participants (76%). The data were analyzed with and without the inclusion of the bilateral surgical cases and the results were unchanged; therefore, the analyses are presented based on the photograph data alone.

Measurement of Sun Exposure

An empirical model to estimate ocular exposure in the UV-B wavelength band has been extensively described in previous publications.17-18 The model for cumulative exposure for a single day is as follows:

\[
H_P = R_P \left( \sum_{k=1}^{12} F(t_k) H_a(t_k) T_{obs} T_{eye} G \right)
\]

where \( R_P \) indicates the ocular-ambient exposure ratio (fixed for the day but variable with season); \( F(t_k) \), the fraction of time spent outdoors in the \( i \)th period of the day (can be variable by month); \( H_a(t_k) \), the global ambient exposure during this day (variable by month and hour of day); \( T_{obs} \) and \( T_{eye} \), fixed factors (between 0 and 1) that reflect the dimmings conferred by the use of hats and eyewear; \( G \), a geographic correction factor that relates the total yearly ambient exposures seen in the Maryland area with locations elsewhere in the world; and \( i \), generic time index. The following formula then is the implementation of this model during a day and over the course of a year:

\[
H_P = \sum_{m=1}^{12} \sum_{i=0}^{18} F(t,m) H_a(t,m) T_{obs}(t,m) T_{eye}(t,m)
\]

where \( m \) indicates index that runs over the months, and \( t \) indicates index that runs over the hours of the day from 5:00 AM (5 hours) to 6:00 PM (18 hours). The exposure units are in Maryland sun-years (MSYs) or the equivalent of 75.9-J/cm² effective integrated energy density (erythemal spectral weighting). The exposure for each person was then summed for each year of life since the age of 30 years, and a cumulative lifetime ocular exposure derived. Those whose cumulative exposure was equal to 0 were those reporting less than 1 hour per day outside in job or leisure activities. Although this group probably has a finite, very low exposure, our model categorizes them as zero.

The ambient exposure levels were obtained from 2 years of measurements made on the Eastern Shore using a UV-B pyranometer (Solar Light Company, Philadelphia, Pa).17,18 The geographic correction factor for jobs and leisure time spent outside Maryland was developed as the result of a semiparametric model developed at the National Aeronautics and Space Administration

JAMA, August 26, 1998—Vol 280, No. 8

Sunlight Exposure and Lens Opacities—West et al

©1998 American Medical Association. All rights reserved.
and described in detail in an earlier publication.\textsuperscript{17} The model does correct for cloud cover in various locations around the globe. The ocular ambient exposure ratios were determined through a series of measurements made on residents of the population of Salisbury as they carried out usual daily activities. The ocular ambient exposure ratios were allowed to vary by season.\textsuperscript{18} Diminution factors for hat use were also based on our measurements in the Salisbury population.\textsuperscript{18} Diminution factors for glasses were based on previous experiments on UV-B attenuation for plastic and glass sunglasses and eyeglasses.\textsuperscript{20} The fraction of time spent outdoors and the use of glasses, sunglasses, and hats were derived from the job and leisure history questionnaire administered to participants. This questionnaire asked participants about their job history since the age of 30 years, time spent outside during the job and leisure time, geographic location of job and leisure activity, and glasses and hat use while outside. In our pilot studies, we were unable to obtain reliable data from this age group on time spent outside and job history, prior to the age of 30 years, so our job history questionnaire began at the age of 30 years.\textsuperscript{23} Based on data from ophthalmologists in Salisbury, plastic lenses were introduced in 1970, and, currently, approximately 85\% of the sample who use any eyewear use plastic lenses; the remaining 15\% use glass lenses. Therefore, we presume that prior to 1970, all spectacles had glass lenses, and between 1970 and the present, a yearly linear increment used plastic lenses.

### Other Variables

Data on age, race, and sex of participants were available from the home questionnaire. Data on diabetes were based on a self-report, validated by use of insulin or oral hypoglycemics or by hospital or physician records. For those who denied presence of diabetes, we included as diabetic patients those patients with a hemoglobin A$_1c$ value greater than 7\%.\textsuperscript{27} In addition, other variables, such as educational level, smoking, and alcohol use, were collected via an interviewer-administered home questionnaire. These variables were evaluated for the relationship to the different types of lens opacities.

### Analyses

Review of our models suggested that original, untransformed data on UV-B exposure were acceptable. Therefore, all analyses are based on untransformed average annual exposure. Analyses were also carried out using cumulative exposure, which is highly correlated with age. By using average annual exposure, the age component of exposure is removed, and the addition of age alone permits other age-related effects, which are also significant, to be in the model of risk of opacities. Differences in exposure by sex and race were assessed using a median test for 2 samples, where a simple linear rank statistic was calculated on the median score.

Data were analyzed initially using simple bivariate analyses. \textit{χ} Tests and trend tests for significance were performed. Logistic regression models with opacity as the dependent variable were created to evaluate the effect of increasing exposure to UV-B, adjusting for other risk factors. In order to present the most parsimonious models, factors that were not associated with the opacities of interest were not entered into the models.

A serially additive expected-dose model was used to further determine possible associations between age of exposure and risk of lens opacities.\textsuperscript{28} In this model, the expected yearly exposure to UV-B is calculated based on all the controls without lens opacities of the same age as the cases. The actual observed exposure for each subject is then compared with the expected exposure calculated from the controls. A paired \textit{t} test is used to test the cumulative difference in observed vs expected exposures. In addition, differences at each age or age category can be explored.

The data from the short questionnaire showed similar distributions in refusals and participants of responses to questions on sun exposure and self-report of vision. Therefore, these variables were not used to determine adjustments for differential response rates. Participants differed from nonparticipants in having more disability, less education, and reporting poorer health status.\textsuperscript{29} The association between UV-B and opacity was evaluated within strata of each of these variables to determine if differential response rate might explain our findings. However, there were no differences in the associations between UV-B exposure and opacities within these factors. Thus, we did not make any further adjustments for refusal rates.

### RESULTS

Of the 2520 participants, 26.4\% were African American and 58\% were female. Of those without cataract surgery, cortical photographs on at least 1 eye were obtained on 94\% and nuclear photographs obtained on 95\%.\textsuperscript{15} Photographs could not be obtained on the rest primarily due to equipment failure or medical contraindication to dilation. There was no statistically significant difference in the clinical grade of opacities in those with and without photographs.\textsuperscript{30} There was a pronounced difference in prevalence of opacity types by racial group (Table 1), with more cortical opacities and fewer nuclear opacities in African Americans (\textit{P}<.05).

There were no pronounced differences in the distribution of average annual ocular UV-B exposure by racial group. However, women had significantly less ocular exposure compared with men (\textit{P}<.05) (Table 2). The average annual exposure for this population-based sample of older men and women was significantly lower than the average annual exposure reported for the occupational group of the Chesapeake Bay watermen, 0.011 MSY vs 0.022 MSY (\textit{P}<.05).

The prevalence of cortical opacity by quartiles of average annual ocular UV-B exposure increased from the lowest to the highest quartile, with a significant difference in the prevalence comparing the highest with the lowest (Table 3). With adjustment for age, race, sex, diabetes status, and education, the test for linear trend of increasing odds with increasing quartile of exposure was significant (\textit{P}=.03). Smoking, education, and alcohol use were not significantly related to cortical opacity and were not included in the model.
With ocular exposure modeled as a continuous variable, the odds of cortical opacity increased 10% with each 0.01 MSY increase in average annual ocular UV-B exposure (Table 4). The relationship was similar when analyses were confined to women and to African Americans (ORs, 1.14 and 1.18, respectively) (Tables 5 and 6). There was no evidence of any relationship between nuclear opacity or PSC opacity and exposure to UV-B, either age adjusted or in multivariate models, which also included race, sex, smoking, diabetes, education, and steroid use (data not shown).

We used the serially additive expected-dose model, where differences in the annual dose by age between cases of cortical opacity and controls without cortical opacity can be compared. There was no age (>30 years) where exposure for cases was much greater than the exposures at other ages (Figure). There were relatively few participants aged 80 years and older, suggesting no particular age of life exposure was found. The excess risk was observed at each age from 30 years and older, suggesting no particular age of life exposures. In the Salisbury study, women had less exposure than men in this population. The previous work showing no association among women was also population.15,16 Which is unlikely due to differences in the prevalences of ocular diseases, notably glaucoma and age-related macular degeneration.29,30 We and others have previously shown a pronounced racial variation in types of lens opacities,15,16 which is unlikely due to different rates of cataract surgery or other methodological issues. It is conceivable that risk factors may operate differently in different racial groups. However, there is still an excess of cortical opacity in the African American population that is not attributable to UV-B exposure or the other risk factors evaluated, such as age, sex, and diabetes status. It is clear that UV-B exposure is a risk factor for cortical opacity in this racial group as well. Further work on risk factors within racial groups is warranted.

Our study did not find any association between UV-B exposure and nuclear American Americans. There are racial differences in the prevalences of ocular diseases, notably glaucoma and age-related macular degeneration.29,30 We and others have previously shown a pronounced racial variation in types of lens opacities,15,16 which is unlikely due to different rates of cataract surgery or other methodological issues. It is conceivable that risk factors may operate differently in different racial groups. However, there is still an excess of cortical opacity in the African American population that is not attributable to UV-B exposure or the other risk factors evaluated, such as age, sex, and diabetes status. It is clear that UV-B exposure is a risk factor for cortical opacity in this racial group as well. Further work on risk factors within racial groups is warranted.

Our study did not find any association between UV-B exposure and nuclear A1c.

**COMMENT**

In a population-based study of older Americans in Salisbury, a detailed model was developed for the assessment of ocular exposure to UV-B.17-19 Using this model for exposure assessment, a significant association between cortical opacities and average annual UV-B exposure was found. The excess risk was observed at each age from 30 years and older, suggesting no particular age of life exposures. In the Salisbury study, women also had lower average annual exposures, but the association of cortical cataract with exposure was still evident and marginally significant.

Our study is the first to document the relationship between ocular exposure to UV-B and risk of cortical opacity in American Americans. There are racial differences in the prevalences of ocular diseases, notably glaucoma and age-related macular degeneration.29,30 We and others have previously shown a pronounced racial variation in types of lens opacities,15,16 which is unlikely due to different rates of cataract surgery or other methodological issues. It is conceivable that risk factors may operate differently in different racial groups. However, there is still an excess of cortical opacity in the African American population that is not attributable to UV-B exposure or the other risk factors evaluated, such as age, sex, and diabetes status. It is clear that UV-B exposure is a risk factor for cortical opacity in this racial group as well. Further work on risk factors within racial groups is warranted.

Our study did not find any association between UV-B exposure and nuclear A1c.

**Table 3.—Odds of Cortical Opacity Comparing Quartiles of Average Annual UV-B Exposure**

<table>
<thead>
<tr>
<th>Quartile of UV-B</th>
<th>Age-Adjusted Odds Ratio (n = 2101)</th>
<th>Multivariate Odds Ratio (n = 2034)</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.004</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00-1.00</td>
</tr>
<tr>
<td>&gt;0.004-0.011</td>
<td>0.98</td>
<td>1.30</td>
<td>0.88-1.92</td>
</tr>
<tr>
<td>&gt;0.011-0.024</td>
<td>0.96</td>
<td>1.32</td>
<td>0.88-1.97</td>
</tr>
<tr>
<td>&gt;0.024</td>
<td>1.14</td>
<td>1.57</td>
<td>1.04-2.38</td>
</tr>
</tbody>
</table>

*Multivariate odds ratios were adjusted for age, sex, race, and diabetes. Sixty-seven persons were missing blood samples for determination of hemoglobin A1c.

**Table 4.—Cortical Opacity and Average Annual UV-B Exposure (n = 2034)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-B</td>
<td>1.10</td>
<td>1.02-1.20</td>
</tr>
<tr>
<td>Female</td>
<td>1.70</td>
<td>1.24-2.33</td>
</tr>
<tr>
<td>African American</td>
<td>4.64</td>
<td>3.53-6.11</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.26</td>
<td>0.83-1.70</td>
</tr>
<tr>
<td>Age</td>
<td>1.09</td>
<td>1.07-1.12</td>
</tr>
</tbody>
</table>

*For every 0.01 Maryland sun-year.

**Table 5.—Risk Factors for Cortical Opacities in Females (n = 1135)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-B</td>
<td>1.14</td>
<td>1.00-1.30</td>
</tr>
<tr>
<td>African American</td>
<td>4.77</td>
<td>3.36-6.77</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.27</td>
<td>0.86-1.88</td>
</tr>
<tr>
<td>Age</td>
<td>1.08</td>
<td>1.05-1.12</td>
</tr>
</tbody>
</table>

*For every 0.01 Maryland sun-year (48 women were missing blood samples for determination of hemoglobin A1c).

**Table 6.—Risk Factors for Cortical Opacities in African Americans (n = 530)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-B</td>
<td>1.18</td>
<td>1.04-1.33</td>
</tr>
<tr>
<td>Female</td>
<td>2.09</td>
<td>1.27-3.44</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.15</td>
<td>0.76-1.72</td>
</tr>
<tr>
<td>Age</td>
<td>1.08</td>
<td>1.04-1.13</td>
</tr>
</tbody>
</table>

*For every 0.01 Maryland sun-year (25 African Americans were missing blood samples for determination of hemoglobin A1c).
opacity, a finding consistent with the Chesapeake Bay Waterman study and other studies as well. 31 The lens absorbs UV-B radiation, with a gradient of absorption from the anterior to the posterior plane of the lens. The anterior cortical surface receives the most radiant energy and thus would be the most likely target for damage. In animal experiments, anterior opacities were also the most common opacities observed. 31

Our study also did not find an association with PSC opacities, although a previous case-control study of PSC opacities in a sample from the same geographic locale found an increased risk associated with UV-B exposure. 32 The previous study also used a detailed assessment of ocular UV-B exposure, although using assumptions more appropriate for the Chesapeake Bay Waterman study. We analyzed our data to mimic the analyses done in the prior study in an effort to reproduce the findings, but there was still no association. The control selection for the earlier study was persons without PSC who had visited an eye care professional at the same time as a case of PSC. Half those controls had no opacities, with cases of PSC having more concomitant cortical opacities than controls. It is possible that the presence of cortical opacities in the cases explained the association.

Age was also an independent predictor of cortical opacity, after adjustment for other factors. This finding suggests that UV-B exposure over the lifetime does not explain the “age” effects in cataractogenesis. Myriad changes occur in the lens with age, including pronounced physical and metabolic changes. 33 Some of these changes are accelerated in cataractogenesis, which may explain the effects of these changes are accelerated in cataractogenesis, which may explain the age, beyond chronologic age, effects. 33

For this population of older persons in Salisbury, the attributable risk for cortical opacity due to higher levels of UV-B exposure is 15%. These data add to the growing body of knowledge that suggests even low levels of UV-B can harm the lens. Measures to avoid ocular exposure to UV-B in sunlight are simple. The wearing of plastic glasses or sunglasses confers excellent protection, and the simple wearing of a hat with a brim decreases ocular exposure by 30% to 50%. These measures should be part of any public health program to increase awareness of sun damage and avoid uncomfortable consequences.

This project was supported by grant P01-AG10184 from the National Institute on Aging, Bethesda, Md. Dr West is a Research to Prevent Blindness Senior Scientist Investigator. Dr Bandeen-Roche is a Brookdale National Fellow. The investigators gratefully acknowledge the efforts of Leslie Wilson, whose knowledge of sun exposure assessment was critical to this project. We are grateful to the SEE team project members: Jennifer Estes, Chris Altson, David Altson, Josh MacIntosh, Jo Ellen Mitchell, Matthew Lynch, Deborah Donoway, and Sherice Harrison.

References