

Association of Surface Ultraviolet B Radiation Levels with Melanoma and Nonmelanoma Skin Cancer in United States Blacks

Gene Pennello,¹ Susan Devesa, and Mitchell Gail

United States Food and Drug Administration, Center for Radiological Devices and Health, Rockville, Maryland 20850 [G. P.], and National Cancer Institute, Division of Cancer Epidemiology and Genetics, Rockville, Maryland 20892 [S. D., M. G.].

Abstract

Ultraviolet B (UVB) radiation exposure increases the risk of skin cancer in whites. Motivated by indications that United States geographic variation of relative skin cancer risk in blacks approaches that in whites, we used Poisson regression to estimate the risk of skin cancer in blacks as a function of average annual surface-levels of UVB radiation, measured by Robertson-Berger meters. United States data were used on deaths in 506 state economic areas, 1970–1994, and on incident cases in the nine areas of the Surveillance, Epidemiology, and End Results Program, 1973–1994. For black males, the age-adjusted relative risk of mortality for a 50% increase in UVB radiation was significantly above one for malignant melanoma, 1970–1994 (1.16; 95% confidence interval, 1.02–1.32) and nearly so for nonmelanoma skin cancer, 1970–1981 (1.18; 95% confidence interval, 1.00–1.39), for which the time period was chosen to avoid AIDS-related deaths from Kaposi's sarcoma. However, for black females, the relative risk of mortality was not significantly elevated for either skin cancer, and, for both black males and females, the relative risk of incidence was not significantly elevated for melanoma in the period 1973–1994. Incidence data on nonmelanoma skin cancer were not available. Although the public health implication is uncertain because of the much lower absolute risk of skin cancer in blacks compared with whites, the findings suggest that sunlight exposure increases skin cancer risk in blacks.

Introduction

Sunlight exposure and low level of skin pigmentation are predominant risk factors for skin cancer in whites. Increased risk in whites of both malignant melanoma and nonmelanoma skin cancer (NMSC),² including BCC and SCC, has been associated

with UVB radiation exposure from sunlight, decreasing latitude, and decreasing level of skin pigmentation (1–5). Furthermore, blacks have much lower melanoma, BCC, and SCC incidence rates than whites (6, 7), and the dose of UV radiation required to produce a minimum perceptible erythema has been estimated to be 6–33 times greater in blacks than in whites (8, 9).

Some previous work suggests that sunlight exposure and low level of skin pigmentation are risk factors for skin cancer in blacks as well as whites. A Howard University Hospital study of 23 blacks with BCC and 291 blacks chosen randomly found that 60% of the former but only 10% of the latter had fair or olive skin (Ref. 10; $P < 0.0001$ for the difference). A survey of NMSC incidence at nine United States locations in 1977–1980 recorded 68 cases among blacks that suggest that NMSC rates increased with decreasing latitude (7). Telephone interview data from cases and controls at these locations indicate that the risk of NMSC was lower for dark-skinned whites than fair-skinned whites, but that NMSC rates increased with increasing UVB radiation level for both groups (3).

The present analysis was motivated by indications that United States geographical variation of relative skin cancer rates in blacks approaches that in whites (11, 12). After this discovery, we sought additional evidence linking skin cancer risk for blacks to potential UVB radiation exposure.

Materials and Methods

Data. We tabulated black and white incident cases of malignant melanoma in the nine areas of the SEER program (13). The nine areas are listed in Table 1. The area associated with a case was determined by place of residence at the time of diagnosis. We tabulated cases diagnosed during 1973–1994. Data were unavailable, however, for Seattle in 1973 and for Atlanta in 1973–1974. We stratified the cases by five anatomic site combinations: (a) the combined face, head, and neck sites; (b) the combined upper limb and shoulder sites; (c) the combined lower limb and hip sites; (d) the trunk site; and (e) site not specified. We could not obtain NMSC incidence data specifically for BCC and SCC because these data are not routinely reportable to SEER except for special surveys (for example, the survey reported in Ref. 2).

We tabulated black and white deaths due to melanoma and NMSC by 506 SEAs in the coterminous United States, *i.e.*, excluding Alaska and Hawaii, using data from the National Center for Health Statistics (14). SEAs are groups of counties defined by the United States Bureau of the Census that do not cross state boundaries and are similar in demography, economy,

Received 8/10/99; revised 11/26/99; accepted 12/23/99.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked *advertisement* in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

¹ To whom requests for reprints should be addressed, at United States Food and Drug Administration, Center for Radiological Devices and Health, OSB/DBS HFZ-542, 1350 Piccard Drive, Rockville, MD 20850.

² The abbreviations used are: NMSC, nonmelanoma skin cancer; BAF, biological amplification factor; CI, confidence interval; MLE, maximum likelihood estimate; PDRR50, percentage decrease in relative risk of skin cancer for a 50% decrease in surface UVB radiation level; RR50, relative risk of skin cancer for a

50% increase in surface UVB radiation; RRSD, relative risk SD; SEA, state economic area; SEER, Surveillance, Epidemiology, and End Results (Program); UVB, ultraviolet B (radiation); BCC, basal cell carcinoma; SCC, squamous cell carcinoma.

Table 1 Estimated annual surface level of UVB radiation in Robertson-Berger counts $\times 10^{-4}$ by SEER area and state^a

SEER areas	
Atlanta	153
Connecticut	108
Detroit	101
Hawaii (Honolulu)	246
Iowa	117
New Mexico (Albuquerque)	197
San Francisco	150
Seattle	95
Utah (Salt Lake City)	136
States	
Alabama	154
Arkansas	196
California (north)	145
California (south)	164
Colorado	158
Connecticut	108
District of Columbia	125
Delaware	124
Florida	175
Georgia	152
Iowa	117
Idaho	129
Illinois	117
Indiana	120
Kansas	138
Kentucky	124
Louisiana	172
Massachusetts	109
Maryland	117
Maine	103
Michigan	100
Minnesota	100
Missouri	133
Mississippi	163
Montana	109
North Carolina	142
North Dakota	105
Nebraska	125
New Hampshire	105
New Jersey	118
New Mexico	195
Nevada	160
New York	104
Ohio	113
Oklahoma	144
Oregon	93
Pennsylvania	113
Rhode Island	110
South Carolina	148
South Dakota	115
Tennessee	141
Texas	180
Utah	133
Virginia	129
Vermont	96
Washington	98
Wisconsin	105
West Virginia	126
Wyoming	137

^a For the SEER areas, the average was obtained for 1977–1980 from meter readings except for Connecticut, Hawaii, and Iowa. For these areas and the states, the average was predicted from latitude, altitude, and cloud cover based on models of 1974–1987 meter readings (4).

climate, physical geography, and culture (15). The SEA associated with a death was determined by place of residence at the time of death. For melanoma, we tabulated deaths during 1970–1994. For NMSC, we were concerned about the potential influence of Kaposi's sarcomas related to AIDS. These deaths were given a separate code beginning in 1987 (14). We tabulated NMSC deaths from 1970–1981 and 1987–1994. For comparison with the analyses of these skin cancer data, we also tabulated and analyzed deaths for all cancers combined from 1970–1981 and 1970–1994.

We calculated age-adjusted rates for incident cases and deaths using corresponding person-years at risk tabulated from the United States Bureau of the Census as sums of annual population estimates. We age-adjusted the rates to the 1970 United States population using the direct method of standardization (16) on 18 age groups: 17 5-year intervals beginning with a group 0–4 years of age and a final interval of 85-plus years of age.

To estimate the effect of UVB radiation exposure on the rates, we used available SEER area and state estimates (Ref. 4, Tables 17-3a and 17-2 therein) of average annual UVB radiation reaching the earth's surface (Table 1). The estimates are based on surface-level readings from meters developed by Robertson (17) and Berger *et al.* (18) that were placed at ground level at various National Weather Service stations. The meters were calibrated to an action spectrum that parallels that for human skin erythema and provide a single reading that weights the UVB wavelengths by their relative erythema response. The estimates are given in Robertson-Berger (R-B) counts $\times 10^{-4}$.

The UVB levels used for the SEER areas were averages of UVB readings taken from 1977–1980 as part of a special survey on NMSC (4), except for Connecticut, Iowa, and Hawaii, which were not included in the survey. For Connecticut and Iowa, we appropriated the UVB levels used for the states. The state UVB levels were based on predictions from a regression model that linearly related the log of UVB to latitude, altitude, and sky cover; the regression model is based on UVB meter readings from 1974–1987 and explains up to 97% of the variation in the readings (4). For Hawaii, meter readings were available only for Mauna Loa, a volcano on which no one lives, and a state estimate was not readily available. We, therefore, predicted the value for Honolulu from the regression model $\log(\text{UVB}) = 15.545 - 0.039(L) - 0.0001038(A)$ [given in Ref. 4], where, for Honolulu, $L = \text{latitude} = 21.32$ degrees and $A = \text{altitude in meters} = 4.0$ meters; this model explains up to 91% of the variation in meter readings (4).

For SEAs, we used the corresponding state levels of UVB. The states include DC and separate areas for northern and southern California (Table 1). The SEAs assigned to northern California were San Francisco, San Jose, Sacramento, Eureka, Santa Rosa, Santa Cruz, Chico, Modesto, and Woodland.

Geographic Variation. Before undertaking this paper, we estimated geographical variation in relative melanoma and NMSC mortality rates for blacks and whites as part of a United States cancer mortality atlas (11). We used the methods derived in Ref. 12 to estimate the RRSD among geographical areas and its SE. These are computed under a Poisson model on age-specific counts with means multiplicative in fixed-age effects and random-area effects. The random-area effects represent relative risks and are assumed to be independently gamma distributed with mean one and SD RRSD. We applied the same methods to the time periods considered here.

Poisson Regression on UVB Level. We assumed that age-specific counts within areas are independently Poisson-distrib-

uted with the log of the Poisson mean additive in the log of the person-years at risk, an age effect, and $\beta(\log x)$, where β is the coefficient of the log of UVB level x . In this model, the relative risk of skin cancer for a proportional increase in UVB level from x to cx is $e^{\beta(\log cx)} \div e^{\beta(\log x)} = c^\beta$. We estimated c^β with $c^{\hat{\beta}}$, where $\hat{\beta}$ is the MLE of β , and we obtained an approximate 95% CI as $c^{[\hat{\beta} \pm 1.96se(\hat{\beta})]}$, where $se(\hat{\beta})$ is the asymptotic SE of $\hat{\beta}$. We chose $c = 1.5$ for a 50% increase in UVB level, and we call $1.5^{\hat{\beta}}$ the RR50. For example, a 50% increase corresponds to living in Texas versus Indiana or in San Francisco versus Michigan (Table 1).

The fractional decrease in relative risk for a proportional decrease in UVB level from cx to x is $(c^\beta - 1) \div c^\beta = 1 - c^{-\beta}$. We estimated this quantity with $1 - c^{-\hat{\beta}}$ and obtained an approximate 95% CI as $1 - c^{-[\hat{\beta} \pm 1.96se(\hat{\beta})]}$. We chose $c = 1.5$ to indicate a 50% decrease in UVB level, and we call the percentage decrease in relative risk, $100 \times (1 - 1.5^{-\hat{\beta}})$, the PDRR50.

Correction for Overdispersion. To account for possible overdispersion in the counts relative to Poisson variation, we assumed the commonly used quasilielihood model that the variance of the counts equals the Poisson variance times a scale factor (19). We estimated the scale factor by the Pearson statistic divided by the degrees of freedom of the model. When the scale factor estimate was >1 , indicating overdispersion, we adjusted $se(\hat{\beta})$ by multiplying by the square root of this estimate. When the scale factor estimate was <1 , indicating underdispersion, to be conservative, we made no adjustment. Underdispersion occurred only in the analyses of black counts (see "Results" section), which were sparse, and we were concerned that the scale factor estimates might be unreliable in these cases.

To check the reliability of the scale factor estimate, we computed the score statistic P'_A derived in (20) to test for overdispersion due to unmodeled random effects that are additive in the log of the Poisson mean. When there are no unmodeled random effects, P'_A converges quickly to the standard normal distribution. If P'_A is positive and large compared with the standard normal distribution, then it indicates overdispersion. If P'_A is negative and large in magnitude compared with the standard normal distribution, then it indicates underdispersion.

Results

Geographic Variation. Table 2 lists MLEs of the geographical variation parameter, RRSD, for melanoma mortality, 1970–1994, and NMSC mortality, 1970–1981, by race and gender. Within each type of skin cancer, the RRSD MLE for black males approaches that for white males. Because of sparse data, each RRSD MLE for black females was unreliably estimated as zero with an infinite SE.

We were surprised that the RRSD MLEs for black males were as large as they were, given that skin cancer mortality rates are much lower in blacks than whites. These results are not influenced by the low random variation of low black rates because the RRSD method separates the random variation of observed rates from the variance of area-specific relative risks, which is the component of interest (12). The results motivated the forthcoming Poisson regressions of skin cancer counts on UVB level to see whether some of the geographical variation in blacks could be explained by UVB radiation exposure.

Rates. Age-adjusted rates for groups of geographical areas defined by tertiles of UVB level give preliminary indications of UVB gradients in skin cancer incidence (Table 3) and mortality

Table 2 Geographical variation of skin cancer mortality risk in United States whites and blacks, 1970–1994^a

	Males				Females			
	Rate quartiles		RRSD		Rate quartiles		RRSD	
	Lower	Upper	MLE	SE	Lower	Upper	MLE	SE
Melanoma, 1970–1994								
Whites	2.42	3.32	0.171	0.008	1.39	1.83	0.143	0.008
Blacks	0.00	0.53	0.155	0.055	0.00	0.41	0.000	Inf ^b
NMSC, 1970–1981								
Whites	0.76	1.31	0.301	0.017	0.33	0.56	0.210	0.014
Blacks	0.00	0.64	0.181	0.083	0.00	0.34	0.000	Inf ^b

^a Geographical variation is measured by the RRSD of geographical areas assuming age-specific counts are Poisson with means multiplicative in fixed-age effects and random relative-risk effects with mean one and standard deviation RRSD. The MLE of RRSD and its SE are computed. Rate quartiles are for age-adjusted rates per 100,000 person-years directly standardized for age to the 1970 United States population.

^b Because of sparse data, the RRSD MLE was unreliably estimated as zero with infinite (Inf) variance.

(Table 4). Rates of melanoma incidence (all sites combined), melanoma mortality, and NMSC mortality indicate patterns of increase with UVB tertile in white males, white females, and black males. The rates of these skin cancers in black females, however, did not increase consistently.

The overall rates of melanoma incidence (all sites combined) and mortality were lower in blacks than in whites, with the white:black rate ratio 2.6 times larger for incidence than for mortality for males and 2.9 times larger for females (Tables 3 and 4). The smaller white:black rate ratios for mortality are consistent with the observed poorer survival rates of blacks compared with whites for melanoma (13).

Relative Risk of Melanoma Incidence. According to Poisson regressions, the relative risk of melanoma incidence, all sites combined, at the nine SEER areas, 1973–1994, increased significantly with increasing UVB radiation level for white males and white females (Table 3). These significant increases are indicated by 95% confidence lower bounds greater than one on RR50. The RR50 MLE was 1.22 for white males and 1.17 for white females. The MLE of PDRR50 was 18.2% for white males and 14.5% for white females.

RR50 MLEs were >1 for black males and black females, but the counts were too sparse to demonstrate significantly increased rates with increasing UVB radiation level. The RR50 and PDRR50 MLEs were, respectively, 1.04 and 4.2% for black males and 1.08 and 7.5% for black females; these values were smaller than the corresponding values for white males and white females. Site-specific analyses reveal large but insignificant RR50 MLEs of 1.27 for black males and 1.51 for black females at the combined face, head, and neck sites, and 1.27 for black males and 1.13 for black females at the combined lower limb and hip sites. The first pair of estimates was based on 14 and 12 cases, respectively, and the second pair on 66 and 108 cases, respectively. The only other RR50 MLEs for blacks that were >1 were 1.76 for black females at unspecified sites based on 14 cases, and 1.11 for black females at the trunk site based on 18 cases.

For each of the site-specific and combined analyses for white males and white females, the RR50 and PDRR50 CIs were adjusted for Pearson scale-factor estimates that were >1 , which indicates overdispersion relative to Poisson variation (Table 3). The resulting wider intervals were justified because, in each case except one (white females, site not specified), the

Table 3 Poisson regressions of melanoma incident counts on UVB radiation levels for the nine SEER areas, 1973–1994

Cancer/Race/Gender	No. of Cases	Age-adjusted rates ^a				Model dof ^b	Dispersion estimates ^c		Relative risk quantities ^d			
		By UVB tertiles			Overall		P'_A	Scale	RR50		PDRR50	
		1st	2nd	3rd					MLE	95% CI	MLE (%)	95% CI
All sites combined												
whites												
males	25,639	12.29	12.24	15.96	12.78	143	69.48	8.58	1.22	1.15–1.30	18.2	13.0–23.1
females	23,053	9.34	9.92	11.44	9.87	143	54.73	6.72	1.17	1.10–1.24	14.5	9.3–19.4
blacks												
males	128	0.75	0.63	1.06	0.77	143	0.36	0.72	1.04	0.75–1.46	4.2	–34.1–31.6
females	173	0.79	0.85	0.69	0.78	143	0.33	0.88	1.08	0.81–1.45	7.5	–24.2–31.1
Face/head/neck												
whites												
males	5,891	2.67	3.15	3.93	3.02	143	10.65	2.46	1.28	1.20–1.38	22.1	16.6–27.3
females	3,270	1.11	1.43	1.50	1.29	143	7.55	1.98	1.24	1.14–1.36	19.7	12.4–26.3
blacks												
males	14	0.07	0.06	0.15	0.08	143	0.33	0.36	1.27	0.48–3.38	21.4	–109.0–70.5
females	12	0.04	0.02	0.12	0.05	143	0.61	0.25	1.51	0.51–4.45	33.6	–96.1–77.5
Trunk												
whites												
males	10,600	5.31	4.68	6.20	5.21	143	44.93	6.04	1.16	1.07–1.25	13.6	6.2–20.3
females	5,500	2.40	2.20	2.85	2.40	143	17.39	3.03	1.13	1.04–1.22	11.3	3.9–18.2
blacks												
males	13	0.08	0.04	0.15	0.08	143	1.01	0.37	0.96	0.33–2.79	–4.1	–201.8–64.1
females	18	0.08	0.05	0.08	0.08	143	–0.12	2.10	1.11	0.30–4.16	9.8	–238.5–76.0
Upper limb and shoulder												
whites												
males	5,085	2.37	2.50	3.28	2.54	143	15.85	2.98	1.28	1.18–1.39	22.1	15.5–28.1
females	5,771	2.30	2.51	3.17	2.50	143	16.30	2.84	1.24	1.15–1.33	19.2	12.8–25.1
blacks												
males	14	0.08	0.09	0.05	0.08	143	–0.23	0.26	0.81	0.28–2.33	–23.2	–253.4–57.1
females	21	0.14	0.05	0.04	0.10	143	0.68	0.33	0.42	0.15–1.16	–136.9	–551.3–13.9
Lower limb and hip												
whites												
males	2,376	1.19	0.99	1.55	1.16	143	9.79	1.84	1.22	1.11–1.34	18.1	10.1–25.5
females	7,522	3.15	3.34	3.47	3.27	143	20.94	2.90	1.13	1.05–1.21	11.3	5.0–17.1
blacks												
males	66	0.35	0.42	0.58	0.40	143	0.83	0.68	1.27	0.81–2.02	21.6	–24.2–50.5
females	108	0.47	0.67	0.35	0.49	143	0.64	0.82	1.13	0.78–1.64	11.8	–27.8–39.1
Site not specified												
whites												
males	1,687	0.75	0.92	1.01	0.85	143	3.52	1.50	1.25	1.13–1.39	20.2	11.8–27.9
females	990	0.39	0.44	0.45	0.42	143	0.89	1.13	1.12	0.99–1.26	10.6	–0.8–20.6
blacks												
males	21	0.16	0.03	0.14	0.13	143	0.13	0.26	0.55	0.22–1.42	–81.0	–365.1–29.6
females	14	0.05	0.06	0.10	0.06	143	–0.21	0.23	1.76	0.65–4.82	43.3	–54.8–79.2
Mean UVB level		101.3	134.3	173.3	136.3							
No. of SEER areas		3	3	3	9							

^a Rates are per 100,000 person-years and age-adjusted directly to the 1970 United States population.

^b dof, (model) degrees of freedom.

^c P'_A is a score statistic that tests for overdispersion due to unmodeled random effects; scale refers to the quasiliikelihood scale factor for over- or underdispersion relative to Poisson variation and was estimated by the Pearson statistic divided by the model dof.

^d Each CI was adjusted by the scale-factor estimate of overdispersion if it was >1, but otherwise was not adjusted.

score statistic for overdispersion (P'_A) was much greater than 1.645, the 95th percentile point of the standard normal distribution. For black males and females, RR50 and PDRR50 CIs were adjusted only for black females, trunk, because, in all of the other cases, the scale factor estimates were <1; in all cases, P'_A was between –1.645 and 1.645, which indicated no adjustment was needed.

Relative Risks of Melanoma and NMSC Mortality. For melanoma mortality at the 506 SEAs in the coterminous United States, 1970–1994, relative risks increased significantly with UVB radiation level for white males, white females, and black males (Table 4). The RR50 MLEs were 1.19 for white males,

1.12 for white females, and 1.16 for black males. Corresponding PDRR50 MLEs were 15.9, 10.5, and 13.6%, respectively. For both whites and blacks, the RR50 MLE was significantly greater in males than in females ($P = 0.0001$ for whites and 0.0439 for blacks), which indicated greater increased risk in males than in females for the same increase in UVB radiation level.

For NMSC mortality at the 506 SEAs, 1970–1981, relative risks increased significantly with UVB radiation level for white males and white females and nearly so for black males (Table 4), the same groups for which significant increases in relative risk were found for melanoma mortality. The RR50

Table 4 Poisson regressions of melanoma and NMSC deaths on UVB radiation level for the 506 SEAs in the coterminous United States

Cancer/Race/Gender	No. of deaths	Age-adjusted rates ^a				Model dof ^b	Dispersion estimates ^c		Relative risk quantities ^d				
		By UVB tertiles			Overall		P'_A	Scale	RR50		PDRR50		
		1st	2nd	3rd					MLE	95% CI	MLE (%)	95% CI	
Melanoma, 1970–1994													
whites													
males	73,162	2.71	2.81	3.30	2.96	9089	23.49	1.14	1.19	1.17–1.21	15.9	14.5–17.2	
females	49,739	1.51	1.56	1.74	1.61	9089	16.11	1.05	1.12	1.10–1.14	10.5	8.9–12.2	
blacks													
males	1,099	0.45	0.42	0.51	0.47	9026	0.86	0.71	1.16	1.02–1.32	13.6	1.6–24.1	
females	1,209	0.39	0.37	0.37	0.37	9028	0.66	0.83	0.96	0.85–1.09	–4.0	–17.7–8.2	
NMSC, 1970–1981													
whites													
males	10,162	0.83	0.99	1.19	1.00	9089	9.31	1.08	1.37	1.32–1.43	27.2	24.2–30.1	
females	6,551	0.39	0.41	0.49	0.43	9089	7.45	1.10	1.19	1.13–1.25	15.9	11.3–20.2	
blacks													
males	670	0.58	0.69	0.68	0.66	8980	0.32	0.93	1.18	1.00–1.39	15.1	–0.3–28.2	
females	515	0.37	0.42	0.39	0.39	8953	–1.21	0.78	1.04	0.86–1.26	3.5	–16.9–20.4	
Mean UVB level		105.4	124.2	159.4	132.4								
No. of SEAs		152	154	200	506								

^a Rates are per 100,000 person-years and age-adjusted directly to the 1970 United States population.

^b dof, (model) degrees of freedom; the value sometimes differed from 18*506 minus 19 parameters because age-specific person-years in SEAs were sometimes zero.

^c P'_A is a score statistic that tests for overdispersion due to unmodeled random effects; scale refers to the quasiliikelihood scale factor for over- or underdispersion relative to Poisson variation and was estimated by the Pearson statistic divided by the model dof.

^d Each CI was adjusted by the scale-factor estimate of overdispersion if it was >1, but otherwise was not adjusted.

MLEs were 1.37 for white males, 1.19 for white females, and 1.18 for black males. The corresponding PDRR50 MLEs were 27.2, 15.9, and 15.1%. For whites, the RR50 MLE was significantly greater in males than in females ($P = 0.0001$), indicating greater increased risk in males than in females for the same increase in UVB radiation level. For blacks, the RR50 MLE was greater in males than in females, but not significantly ($P = 0.3251$).

For white males ($P = 0.0001$) and white females ($P = 0.0241$), the RR50 MLE was significantly greater for NMSC than for melanoma, which indicated greater increased risk of NMSC than melanoma for the same increase in UVB radiation level. For black males ($P = 0.8682$) and black females ($P = 0.5220$), the RR50 MLE was also greater for NMSC than melanoma, but not significantly.

For each of the mortality analyses for white males and white females, the RR50 and PDRR50 CIs were adjusted for overdispersion by scale-factor estimates that were >1, and the corresponding score statistics P'_A were much greater than 1.645, which indicated the need for adjustment (Table 4). For black males and black females, the CIs were not adjusted because the scale factor estimates were <1, and P'_A s were between –1.645 and 1.645.

For NMSC mortality for the time periods 1970–1981 and 1987–1994 combined (the latter period excluding AIDS-related deaths) RR50 MLEs for white males and white females were slightly smaller than they were for 1970–1981 considered alone but still significant, which indicated increased relative risk (results not shown). However, the RR50 MLE for black males was only 1.00, indicating no increase in relative risk, in stark contrast to its nearly significant value of 1.18 for the 1970–1981 data considered alone (Table 4).

For comparison with the skin cancer mortality analyses, we obtained RR50s for mortality from all cancers combined for each of the time periods 1970–1981 and 1970–1994. For each time period and each of the four race-gender groups, the RR50 was significantly less than one, which indicated decreased risk with increasing UVB level (results not shown).

Discussion

We found that, for black males, age-adjusted mortality rates of melanoma 1970–1994 increased significantly, and those of NMSC 1970–1981 increased nearly significantly with increasing levels of surface UVB radiation. We did not find corresponding significant increases in black females, nor did we find significant increases in incidence rates of melanoma, 1973–1994, in black males or black females. A previous United States study indicated that NMSC incidence rates for blacks increased with decreasing latitude (7), but we are unaware of previous United States studies that indicated that melanoma incidence or mortality rates for blacks increased with increasing UVB radiation level or with decreasing latitude.

The nearly significant increase in NMSC mortality in black males disappeared, however, when the data for 1970–1981 were combined with the data for 1987–1994 that supposedly excluded AIDS-related deaths. In 1982–1986, the incidence of Kaposi's sarcoma rapidly rose in association with increased cases of AIDS (Ref. 13, p. 215), which make NMSC incidence and mortality data difficult to interpret. Beginning in 1987, AIDS-related Kaposi's sarcoma deaths were supposed to be coded to the human immunodeficiency virus infection if AIDS was mentioned on the death certificate, and to NMSC otherwise (14). Perhaps some of the AIDS-related NMSC deaths after 1986 were reported as skin cancer without specifying AIDS on the death certificate, diluting the potential observable association with UVB radiation. The relative impact of misclassifying AIDS-related NMSC is much greater for blacks than for whites because non-AIDS-related NMSC is much more frequent among whites than blacks.

Melanoma incidence and mortality rates have increased significantly over time for whites but not for blacks. Estimated annual percent changes in rates for 1973–1996 indicate, for melanoma mortality, a 1.0% significant decrease for black males and a 0.0% increase for black females; for melanoma incidence, they indicate an increase for black males and a decrease for black females, neither of which is significant (21).

At the same time, melanoma mortality and incidence rates for white males and white females have increased significantly from 0.6 to 4.4% (21). Melanoma survival rates are poorer for blacks than whites (13), and the significant decrease in black-male melanoma mortality could indicate an improvement in timely diagnosis and treatment. Detection of a consistent time trend for melanoma incidence among blacks is hampered by lack of power due to very low rates for blacks.

The UVB measurements that were used were not representative of individual cumulative exposure to UVB but rather were average annual surface levels in geographical areas corresponding to residence at the date of diagnosis. Furthermore, our use of average annual surface levels for 1977–80 and 1974–1987 does not reflect UVB levels from 1970 to 1994, during which skin cancer data were collected, nor do they reflect yearly changes in UVB levels due to changes in industrialization, motoring, the ozone hole, sunspot activity, and other factors. Therefore, the effects of UVB exposure on skin cancer rates are probably diluted by our use of this surrogate measure. One possible explanation for our failure to link melanoma and NMSC mortality with UVB level for black females is that the UVB measurements are less representative of actual exposure in females than in males, who have been estimated to spend 1.5–2 times more time outdoors (3). Other factors that could explain individual variation in UVB exposure within geographical areas include outdoor recreational habits and the mobility of the United States population. In particular, the migration of blacks from the South to other parts of the United States during this century could lead to the underestimation of the lifetime cumulative exposure of blacks outside the South.

Nonetheless, the same UVB measurements that we used for SEER areas have been used to associate UVB exposure with NMSC incidence (3, 4). As a reviewer has pointed out, we could have used theoretical UVB levels based on applying radiative transfer models to satellite-based measurements of ozone. Such theoretical measurements have indicated increases in UVB levels over time because of ozone depletion (22), although Robertson-Berger meter readings have not indicated increases over a similar time period (23). A possible explanation for the discrepancy is that ozone-based measurements do not account for possible increases in air pollution. Although the time trends are different, the area-specific UVB levels for each method could be proportional, in which case, the use of either of the two sets of levels would lead to essentially the same results.

Our study can be compared with other melanoma incidence studies that report the biological amplification factor (BAF), which is the limit of the ratio of the percent increase in skin cancer to the percent increase in UVB as the latter approaches zero. In symbols, for a model relating rate R to UVB level x , the BAF is

$$\frac{\frac{dR}{R}}{\frac{dx}{x}}$$

In our model, $\text{BAF} = \beta$, as defined in the “Materials and Methods” section, and is constant over x . For melanoma incidence, the estimated BAFs in our study were 0.5 (95% CI, 0.4–0.5) for white males and 0.4 (95% CI, 0.3–0.4) for white females. Krickler *et al.* (24) estimated this BAF to be between 0.3 and 2.5, and Scotto and Fears (25) estimated it between 0.6 and 0.8 for males and 0.5 and 1.0 for females, depending on body site. All of these estimates depend on the time period,

geographical locations, and action spectrum used to compute the UVB dose. Our BAFs are slightly lower, probably because they encompass more recent time periods, and the strength of the association of melanoma risk with UVB has decreased over time, as implied by associations with latitude (26).

The estimated relative risk of mortality was greater for NMSC than for melanoma for the same increase in UVB level for white males, white females, black males, and black females. Although the differences were significant only for white males and white females, the overall pattern suggests that the etiological role that sunlight plays may be more direct for NMSC than for melanoma for both whites and blacks. The anatomical site distribution of NMSC in whites is weighted towards the frequently sun-exposed face, head, and neck sites (4, 7, 27, 28), which suggests that it is associated primarily with chronic sun exposure (29). In contrast, the distribution of melanoma in whites is weighted towards the face, head, and neck in older age groups but towards the infrequently sun-exposed trunk in males and the trunk and leg in females in younger age groups (30–32), which suggests that part of it is associated with chronic sun exposure, and part by recreational sun exposure (29). In contrast, the distributions of NMSC (7) and melanoma (6) in blacks are weighted more towards infrequently sun-exposed sites than frequently sun-exposed sites, probably because of the protection from sunlight afforded by melanin. A special review of medical documents revealed that on the sole of the foot, where sun exposure has presumably little effect, United States whites and blacks have similar melanoma incidence rates (33). Routinely coded data on melanoma incidence are available at five general site combinations, which we studied individually for UVB effects. For black males and black females, melanoma incidence rates increased (insignificantly) with increasing UVB level at the face, head, and neck sites combined and at the lower limb and hip sites combined, suggesting that both recreational and chronic sun exposure may contribute to the risk of melanoma in blacks. However, the site-specific rates for blacks were not consistent with those for whites in that at the trunk site, rates were much higher for white males than for white females, and, at the lower limb and hip sites, rates were much lower for white males than for white females, in accordance with other studies; yet, at both of these site combinations, the rates for black males and black females were about equal (Table 3). Possible explanations include melanin protection from sunlight and the lack of power to detect differences between very low black male and black female rates.

The major limitation of a study of skin cancer mortality rates is that early treatment may prevent death from melanoma and from NMSC, especially the common BCC and SCC forms of NMSC. Thus, factors such as low socioeconomic status that inhibit access to timely diagnosis and treatment could influence skin cancer mortality rates. In order for such factors to confound the association between UVB radiation exposure and skin cancer mortality, poor access to treatment would also need to be associated with latitude. Treatment of prostate (34) and breast cancer (35) has been found to vary geographically in the United States, although not in a consistent north-to-south fashion. It is possible that access to treatment of skin cancer is poorer in more southern latitudes, resulting in higher mortality rates in such locations, but it seems more likely that the latitude effects on mortality reflect biological effects of UVB radiation exposure. If poorer access to treatment were associated with latitude, then one might expect mortality rates for all cancers combined to increase with UVB radiation level, but these rates decreased significantly for all of the four race-gender groups. One might also expect the risk increase in males and females to

be about the same for the same increase in UVB level, but it was significantly smaller for black females than black males for melanoma.

Another factor that could confound associations of UVB radiation exposure with skin cancer is geographical variation of skin color. Light skin color has been associated with increased risk of NMSC among whites (1–5) and with BCC among blacks (10). Therefore, our geographical associations of UVB radiation exposure with skin cancer rates among black males could be explained by a higher prevalence of lighter-skinned blacks in more southern latitudes. We are unaware, however, of empirical data demonstrating that the proportion of admixture of blacks and whites varies by latitude or that the migration of blacks from the South to the rest of the United States during this century varied by skin color.

A reviewer pointed out that since the end, centuries ago, of the trans-Atlantic importation of slaves, a gradual depigmentation of North American blacks may have occurred because of the lack of an environmental basis for skin pigmentation, leading to increased risk of skin cancer caused by UV radiation exposure. We are unaware of studies that compare the skin color of African-Americans to that of native-African blacks. An extensive review of evolutionary theories of skin color is given in Robins (36).

Future case-control studies of incident skin cancer could help to clarify the role of UVB radiation exposure on the risk of melanoma and NMSC in blacks. However, even if increases in risk are confirmed for blacks and other nonwhites, the absolute increases in risk for these population groups will be much smaller than for whites, because these groups have incidence rates much lower than whites (Table 3; Refs. 6, 7). For example, based on the incidence rates in Ref. 7, an increase in UVB radiation exposure that doubles the incident risk of BCC increases the incidence rate in blacks from 2 to only 4 cases per 100,000 person-years at risk, whereas it increases the incident rate in whites from 360 to 720. Thus, care would be required to fashion recommendations for prevention, such as sun-blocking agents, that are warranted and acceptable for blacks and other nonwhite populations.

References

- National Institutes of Health. Summary of the consensus development conference on sunlight, ultraviolet radiation, and the skin. *J. Am. Acad. Dermatol.*, 24: 608–612, 1991.
- Scotto, J., Fears, T. R., and Fraumeni, J. F., Jr. Incidence of Non-melanoma Skin Cancer in the United States (DHEW Publication No. (NIH) 82-2433). Washington, DC: United States Government Printing Office, 1983.
- Scotto, J. Nonmelanoma skin cancer—UVB effects. *In: J. G. Titus (ed.), Effects of Changes in Stratospheric Ozone and Global Climate, Vol. 2: Stratospheric Ozone*, pp. 33–61. Washington DC: United States Environmental Protection Agency, 1986.
- Scotto, J., Fears, T. R., and Fraumeni, J. F., Jr. Solar radiation. *In: D. Schottenfeld and J. F. Fraumeni, Jr. (eds.), Cancer Epidemiology and Prevention, Ed. 2*, pp. 355–372. New York: Oxford University Press, 1996.
- Armstrong, B. K., and Krickler, A. Epidemiology of sun exposure and skin cancer. *Cancer Surv.*, 26: 133–153, 1996.
- Cress, R. D., and Holly, E. A. Incidence of cutaneous melanoma among non-Hispanic whites, Hispanics, Asians, and Blacks: an analysis of California cancer registry data, 1988–93. *Cancer Causes Control*, 8: 246–52, 1997.
- Scotto, J., Fears, T. R., Kraemer, K. H., and Fraumeni, J. F., Jr. Nonmelanoma skin cancer. *In: D. Schottenfeld and J. F. Fraumeni, Jr. (eds.), Cancer Epidemiology and Prevention, Ed. 2*, pp. 1313–30. New York: Oxford University Press, 1996.
- Olson, R. L., Gaylor, J., and Everett, M. A. Skin color, melanin, and erythema. *Arch. Dermatol.*, 108: 541–544, 1973.
- Kollias, N., Sayre, R. M., Zeise, L., and Chedekel, M. R. Protection by melanin. *J. Photochem. Photobiol. B*, 9: 135–160, 1991.
- Halder, R. E., and Bridgeman-Shah, S. Skin cancer in African Americans. *Cancer (Phila.)*, 75: 667–673, 1995.
- Devesa, S. S., Grauman, D. G., Blot, W. J., Pennello, G. A., Hoover, R. N., and Fraumeni, J. F., Jr. Atlas of Cancer Mortality in the United States, 1950–94 (NIH Publication No. 99-4564). Washington, DC: United States Government Printing Office, 1999.
- Pennello, G. A., Devesa, S., and Gail, M. Using a mixed effects model to estimate geographic variation in cancer rates. *Biometrics*, 55: 774–781, 1999.
- Ries, L. A. G., Kosary, C. L., Hankey, B. F., Miller, B. A., Harrias, A., and Edwards, B. K. (eds.). SEER Cancer Statistics Review, 1973–1994 (NIH Publication No. 97-2789). Bethesda, MD: National Cancer Institute, 1997.
- National Center for Health Statistics. Health, United States, 1996–97, and Injury Chartbook (DHHS Publication No. (PHS) 97-1232). Hyattsville, MD: National Center for Health Statistics, 1997.
- United States Bureau of the Census. United States Census of Population: 1960, Number of Inhabitants, United States: Summary Final Report PC (1)-1A. Washington, DC: United States Government Printing Office, 1966.
- Breslow, N. E., and Day, N. E. Statistical methods in cancer research, Vol. 2: The Design and Analysis of Cohort Studies. IARC Sci. Publ. no. 82. Lyon, France: IARC, 1987.
- Robertson, D. F. Solar ultraviolet radiation in relation to sunburn and skin cancer. *Med. J. Aust.*, 2: 1123–1132, 1968.
- Berger, D., and Robertson, D. F., Davies, R. E., and Urbach, F. Field measurements of biologically effective UV radiation. *In: Impacts of Climatic Change of the Biosphere*. CIAP monograph 5, Department of Transportation DOT-TST-75-55, pp. 2-235–2-263. Springfield, VA: NTIS, 1975.
- McCullagh, P., and Nelder, J. A. Generalized Linear Models, Ed. 2. London: Chapman and Hall, 1989.
- Dean, C. B. Testing for overdispersion in Poisson and binomial regression models. *J. Am. Stat. Assoc.*, 87: 451–457, 1992.
- Ries, L. A. G., Kosary, C. L., Hankey, B. F., Miller, B. A., Clegg, L., and Edwards, B. K. (eds.), SEER Cancer Statistics Review, 1973–1996. Bethesda, MD: National Cancer Institute, 1999.
- Madronich, S., and De Grujil, F. R. Skin cancer and UV radiation. *Nature (Lond.)*, 366: 23, 1993.
- Scotto, J., Cotton, G., Urbach, F., Berger, D., and Fears, T. Biologically effective ultraviolet radiation: surface measurements in the United States, 1974 to 1985. *Science (Washington, DC)* 239: 762–764, 1988.
- Krickler, A., Armstrong, B. K., Jones, M. E., and Burton, R. C. Health, Solar UV Radiation and Environmental Change. Lyon, France: IARC, WHO, 1993.
- Scotto, J., and Fears, T. R. The association of solar ultraviolet and skin melanoma incidence among caucasians in the United States. *Cancer Investig.* 5: 275–283, 1987.
- Lee, J. A. H. Declining effect of latitude on melanoma mortality rates in the United States. *Am. J. Epidemiol.*, 146: 413–417, 1997.
- Glass, A. G., and Hoover, R. N. The emerging epidemic of melanoma and squamous cell skin cancer. *J. Am. Med. Assoc.*, 262: 2097–2100, 1989.
- Gallagher, R. P., Ma, B., McLean, D. I., Yang, C. P., Ho, V., Carruthers, J. A., and Warshawski, L. M. Trends in basal cell carcinoma, squamous cell carcinoma, and melanoma of the skin from 1973 through 1987. *J. Am. Acad. Dermatol.*, 23: 413–421, 1990.
- Marks, R. An overview of skin cancers: incidence and causation. *Cancer (Phila.)*, 75: 607–612, 1995.
- Elwood, J. M., and Gallagher, R. P. Body site distribution of cutaneous malignant melanoma in relationship to patterns of sun exposure. *Int. J. Cancer*, 78: 276–280, 1998.
- Holman, C. D. J., Armstrong, B. K., and Heenan, P. J. Relationship of cutaneous malignant melanoma to individual sunlight-exposure habits. *J. Natl. Cancer Inst.*, 76: 403–414, 1986.
- Elder, D. E. Melanoma and other specific nonmelanoma skin cancers. *Cancer (Phila.)*, 75 (Suppl.): 245–256, 1995.
- Stevens, N. G., Liff, J. M., and Weiss, N. S. Plantar melanoma: is the incidence of melanoma of the sole of the foot really higher in blacks than whites? *Int. J. Cancer*, 45: 691–693, 1990.
- Harlan, L., Brawley, O., Pommerenke, F., Wali, P., and Kramer, B. Geographic, age, and racial variation in the treatment of local/regional carcinoma of the prostate. *J. Clin. Oncol.*, 13: 93–100, 1995.
- Farrow, D. C., Hunt, W. C., and Samet, J. M. Geographic variation in the treatment of localized breast cancer. *N. Engl. J. Med.*, 326: 1097–1101, 1992.
- Robins, A. H. Biological perspectives on human pigmentation. New York: Cambridge University Press, 1991.