ORIGINAL ARTICLE

Sunlight and mortality from breast, ovarian, colon, prostate, and non-melanoma skin cancer: a composite death certificate based case-control study

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Objectives: To explore whether mortality from female breast, ovarian, colon, and prostate cancer were negatively associated with exposure to sunlight.

Methods: A death certificate based case-control study of mortality was conducted into five cancers: female breast, ovarian, colon, prostate, and non-melanoma skin cancer (as a positive control) to examine associations with residential and occupational exposure to sunlight. Cases were all deaths from these cancers between 1984 and 1995 in 24 states of the United States. Controls, which were age frequency matched to a series of cases, excluded deaths from cancer and certain neurological diseases. Multiple logistic regression was used in a model that included age, sex, race, residential exposure to sunlight (based on region), and socioeconomic status, occupational exposure to sunlight, and physical activity (the last three based on usual occupation).

Results: Residential exposure to sunlight was negatively and significantly associated with mortality from female breast, ovarian, prostate, and colon cancer. Only female breast and colon cancer, however, also showed significant negative associations with jobs with the highest occupational exposure to sunlight (odds ratio (OR) 0.82 (95% confidence interval (95% CI) 0.70 to 0.97) for female breast cancer; OR 0.90 (95% CI 0.86 to 0.94) for colon cancer). For both cancers, the negative association with occupational sunlight was greatest in the geographical region of highest exposure to sunlight and was independent of physical activity on the job. Non-melanoma skin cancer, as expected, was positively associated with both residential and occupational sunlight.

Conclusions: In this exploratory study, unlike mortality from non-melanoma skin cancer, mortality from female breast cancer and colon cancer were negatively associated with both residential and occupational sunlight.

It is well established that exposure to sunlight contributes to non-melanoma skin cancer.[1] By contrast, several ecological studies suggest that sunlight may protect against female breast,[2 3] ovarian,[4] prostate,[5 6] and colon cancer,[7] all diseases that contribute to a substantially higher proportion of cancer mortality in the western industrialised world. Some analytical studies, although not all,[8–11] also suggest a protective association between circulating vitamin D in blood, which is largely derived from sunlight,[12] or dietary vitamin D and colorectal cancer,[13 14] female breast cancer,[15 16] and prostate cancer.[17]

To our knowledge, no epidemiological study has examined the relation between ovarian, prostate, or colon cancers and sunlight from non-residential sources, and only one, a recent cohort study,[15] has examined these factors for breast cancer. We conducted a set of death certificate based case-control studies of mortality from female breast, ovarian, prostate, colon, and non-melanoma skin cancers in the United States. As an improvement over geography based ecological mortality studies, we assessed potential exposure to sunlight based on occupational data on individual death certificates. The findings for breast, ovarian, colon, and prostate cancer were contrasted with those for non-melanoma skin cancer, which served as a positive control.

MATERIALS AND METHODS

The National Cancer Institute, the National Institute for Occupational Safety and Health, and the National Center for Health Statistics maintain a database of all deaths in 24 states (1985–95), which codes occupation, state of residence at birth and at death, and other information from death certificates.[18] Cases for this study included all deaths from female breast cancer (international classification of diseases, ninth revision (ICD-9), (code 174), ovarian cancer (code183), colon cancer (code 153), prostate cancer (code185), and non-melanoma skin cancer (code 173). Non-melanoma skin rather than melanoma was selected as a positive control because the association between sunlight and melanoma is more complex, with age at exposure and intermittent intense exposure thought to have a role.[1] A common set of controls was used across a series of case-control studies on cancer and neurological mortality and solar radiation.[19] Deaths from cancer (ICD 140–239), multiple sclerosis (ICD 340), and some diseases of the central nervous system (ICD 330–337), were excluded from the controls because of their potential association with exposure to sunlight. Controls were frequency matched by 5 year age group to the combined group of breast cancer, ovarian cancer, prostate cancer, colon cancer, and the other causes of death in the case series. Controls were limited to women for female breast and ovarian cancer, and to men for prostate cancer. The controls represent a one to one ratio with the most common causes of death in the series (colon cancer), but a ratio of about 25 to one with skin cancer.

Residential exposure to sunlight was assessed by state residence and birthplace recorded on the death certificate. We assigned each state one of three levels of solar radiation based

Abbreviations: ICD-9, 9th revision of the international classification of diseases; 1,25(OH)$_2$D, 1-α-hydroxyvitamin D3

Table 1 Characteristics of cancer cases and controls (data expressed as numbers of participants, United States, 1984–95)

	Non-melanoma skin cancer		Breast cancer		Ovarian cancer		Prostate cancer		Colon cancer	
	Cases n=6565	Controls n=153502	Cases n=130261	Controls n=70081	Cases n=39002	Controls n=70081	Cases n=97873	Controls n=83421	Cases n=153511	Controls n=153502
Age:										
<50	616	14704	19946	4102	3439	4102	317	10602	7454	14704
50–59	853	15976	21765	5295	5680	5295	2991	10681	14594	15976
60–69	1462	32336	31694	12116	10537	12116	17111	20220	34555	32336
70–79	1655	45896	31587	20960	11659	20960	38348	24936	49639	45896
⩾80	1979	44590	25269	27608	7687	27608	39106	16982	47269	44590
Sex:										
Female	2073	70081	130261	70081	39002	70081	0	0	79791	70081
Male	4492	83421	0	0	0	0	97873	83421	73720	83421
Race:										
White	5930	133279	115901	60846	35797	60846	81524	72433	137146	133279
Black	596	18699	13468	8612	2895	8612	15691	10087	15335	18699
Other	39	1524	892	623	310	623	658	901	1030	1524
Residence*:										
Low	1321	33696	32961	15572	9769	15572	22249	18124	38966	33696
Med	2198	50252	40854	23112	12362	23112	30035	27140	50495	50252
High	1410	31247	22622	13874	6862	13874	19302	17373	24695	31247
Other†	1636	38307	33824	17523	10009	17523	26287	20784	39355	38307
Occupation:										
Indoor	3024	71529	69298	30215	20333	30215	51219	41314	78079	71529
Mixed	1398	28312	5224	2182	1552	2182	27715	26130	25144	28312
Outdoor	374	6060	411	258	136	258	6088	5802	4163	6060
Farmer	410	6648	298	271	108	271	10609	6377	5606	6648
Other‡	1359	40953	55030	37155	16873	37155	2242	3798	40519	40953
Physical activity:										
Sedentary	9.28	21660	25989	9328	7447	9328	14428	12332	24572	21660
Low	1509	3643	24314	10215	7179	10215	27661	23428	35391	33643
Med	2370	63510	72116	45239	22017	45239	20990	18271	65247	63510
High	1632	31744	6310	4417	1929	4417	32959	27327	25846	31744
Other§	126	2945	1532	882	430	882	1835	2063	2455	2945
Socioeconomic status:										
1 Low	1105	22112	7298	5283	2231	5283	21883	16829	18351	22112
2	1198	26184	13586	7574	4152	7574	18852	18610	22600	26184
3	1800	40017	30242	11609	8839	11609	33214	28408	43334	40017
4	776	17944	21065	7414	6029	7414	14103	10530	21528	17944
5 High	285	4777	2443	604	662	604	6606	4173	5950	4777
Other¶	1401	42468	55627	37597	17089	37597	3215	4871	41748	42468

*Levels of exposure to sun were categorised based on annual mean daily solar radiation reported by Garland *et al*[7] for state reported as residence and birthplace. This was sometimes outside the 24 states in which deaths occurred. "Low" included the following states and other areas: Alaska, Connecticut, *Maine*, Massachusetts, Michigan, Minnesota, *New Hampshire*, New York, *Ohio*, Oregon, Pennsylvania, *Rhode Island*, *Vermont, Washington, Wisconsin*, Canada. "Moderate" included Arkansas, Delaware, District of Columbia, *Idaho*, Illinois, *Indiana*, Iowa, *Kansas, Kentucky*, Maryland, *Missouri*, Montana, *Nebraska, New Jersey, North Carolina*, North Dakota, South Carolina, *Tennessee*, Virginia, and *West Virginia*. "High" included Alabama, Arizona, California, *Colorado*, Florida, *Georgia*, Hawaii, Louisiana, Mississippi, *Nevada, New Mexico, Oklahoma, South Carolina*, Texas, *Utah*, Wyoming, Puerto Rico, Virgin Islands, Guam, Cuba, and Mexico. (States in italics identified are the 24 states from the mortality database.); †Other refers to those whose region of residence differed between birth and time of death; ‡Other refers to homemakers, and those with no or unidentified occupations whose exposure to sunlight could not be inferred; §Other refers to those with unidentified occupations whose level of physical activity could not be inferred; ¶Other refers to homemakers, students, volunteers, and those with no or unidentified occupations.

on data from the United States Weather Bureau.[7] The 24 states reflected all regions of the country (table 1). Subjects were limited to those who resided in the same solar radiation region at birth and at death (about 75%) to exclude those most likely to have varied solar residential histories.

Occupational exposure to sunlight was based on usual occupation from the death certificate (as reported by next of kin) and classified by an industrial hygienist (MD) into four categories: indoor work, work that combined indoor and outdoor work, outdoor work by non-farmers, and farming (analyzed with dummy variables). Farmers were categorised separately because several studies have suggested that farmers are at increased risk of prostate[20–23] and other cancers.[24] Those with unidentified occupations or positions that could not be classified were controlled for separately. Occupation was also used to assess socioeconomic status (based on a scoring method developed by Green).[24] Also, physical activity (high, moderate, low, and sedentary), which growing evidence suggests may protect against several forms of cancer,[25 26] was assessed based on occupation.

We used multivariate models of potential occupational and residential exposure to solar radiation that included age, sex, race, socioeconomic status, and physical activity. The models were applied to the entire population; as well as strata based on residence, level of physical activity, and race, as a further check on potential confounding by these variables.

The measure of association was the mortality odds ratio (OR) and 95% confidence interval (95% CI) derived by standard logistic regression methods in SAS.[27]

RESULTS

The distribution of cases and controls for non-melanoma skin, female breast, ovarian, prostate, and colon cancer deaths by age, sex, race, residence, occupational exposure to sunlight, and physical activity are shown in table 1. Cases varied from about 6% of cases of skin cancer engaged in non-farming outdoor work to less than 1% among cases of breast and ovarian cancer.

Table 2 reports the ORs for residential and occupational exposure to sunlight, as well as physical activity and socioeconomic status, adjusted for age, sex, race, and the other factors in the table. As expected, the odds ratio for non-melanoma skin cancer was greatest in the region of the United States

Table 2 Odds ratios (95% CIs) for non-melanoma skin, female breast, ovarian, colon, and prostate cancer mortality associated with residential exposure to sunlight, occupational exposure to sunlight, occupational physical activity, and socioeconomic status, adjusted for age, sex, race, and other factors in the table

	Non-melanoma skin cancer		Breast cancer		Ovarian cancer		Prostate cancer		Colon cancer	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Residence*:										
Low	1.0		1.0		1.0		1.0		1.0	
Med	1.14	1.07 to 1.23	0.84	0.82 to 0.86	0.90	0.87 to 0.93	0.89	0.86 to 0.91	0.90	0.88 to 0.92
High	1.23	1.14 to 1.33	0.74	0.72 to 0.76	0.84	0.81 to 0.88	0.90	0.87 to 0.93	0.73	0.71 to 0.74
Occupation:										
Indoor	1.0		1.0		1.0		1.0		1.0	
Mixed	1.01	0.93 to 1.09	1.03	0.97 to 1.09	1.02	0.94 to 1.10	1.00	0.97 to 1.03	0.98	0.96 to 1.00
Outdoor	1.30	1.14 to 1.47	0.82	0.70 to 0.97	0.94	0.75 to 1.17	1.00	0.96 to 1.05	0.90	0.86 to 0.94
Farmer	1.15	1.00 to 1.32	0.92	0.77 to 1.10	1.12	0.88 to 1.41	1.16	1.11 to 1.22	1.04	0.99 to 1.09
Physical activity:										
Sedentary	1.0		1.0		1.0		1.0		1.0	
Low	0.91	0.83 to 1.01	0.95	0.91 to 0.99	0.97	0.92 to 1.02	1.04	0.99 to 1.08	0.97	0.94 to 0.99
Med	0.91	0.82 to 1.01	0.79	0.76 to 0.82	0.82	0.78 to 0.87	1.01	0.97 to 1.06	0.92	0.89 to 0.95
High	0.86	0.76 to 0.98	0.79	0.73 to 0.85	0.82	0.75 to 0.91	1.02	0.97 to 1.07	0.89	0.86 to 0.92
Socioeconomic status:										
1 Low	1.0		1.0		1.0		1.0		1.0	
2	0.97	0.87 to 1.08	0.99	0.93 to 1.06	1.00	0.92 to 1.09	1.05	1.01 to 1.09	1.01	0.98 to 1.05
3	0.92	0.83 to 1.03	1.28	1.20 to 1.36	1.24	1.14 to 1.35	1.23	1.18 to 1.28	1.21	1.17 to 1.25
4	0.91	0.80 to 1.04	1.48	1.39 to 1.58	1.41	1.29 to 1.53	1.48	1.40 to 1.56	1.25	1.20 to 1.30
5 High	1.08	0.92 to 1.27	1.60	1.43 to 1.78	1.52	1.32 to 1.75	1.74	1.64 to 1.84	1.45	1.38 to 1.53

Footnotes as for table 1.

with highest exposure to sunlight (OR 1.23; 95% CI 1.14 to 1.33) and among workers with non-farming outdoor jobs (OR 1.30; 95% CI 1.14 to 1.47). Socioeconomic status was not clearly related to risk of skin cancer, but occupational physical activity seemed to be negatively associated with the disease. The association with occupational exposure to sunlight was increased in both white Americans and African-Americans, although the association with residential sunlight was limited to white people (data not shown).

Residential exposure to sunlight was negatively and significantly associated with mortality from female breast, ovarian, prostate, and colon cancer, among those in the highest and medium sunlight region (table 2). Risks in the highest region ranged from OR 0.73 (95% CI 0.71 to 0.74) for colon cancer to OR 0.90 (95% CI 0.87 to 0.93) for prostate cancer. The risks were consistent among white and black people except for prostate cancer, where risk for black men was increased in the highest sunlight region (data not shown).

For occupational exposure to sunlight, however, only female breast and colon cancer showed significant negative associations, and only for non-farming outdoor jobs. The adjusted OR was 0.82 (95% CI 0.70 to 0.97) for female breast cancer, and 0.90 (95% CI 0.86 to 0.94) for colon cancer. The negative associations characterised both white and black cases of breast and colon cancer (data not shown). Farming jobs were associated with increased ORs for prostate cancer, whereas occupational physical activity was negatively associated with each of the cancers except prostate cancer. Each cancer other than skin cancer was positively associated with increasing socioeconomic status.

Table 3 gives the ORs for mortality from non-melanoma skin, female breast, ovarian, prostate, and colon cancer and occupational exposure to sunlight, for each residential strata and for those with jobs with high (high/moderate) and low (low/sedentary) physical activity, also adjusted for age, sex, race, socioeconomic status, and physical activity. For non-melanoma skin cancer, the OR was increased in each region and physical activity strata for those with non-farming outdoor jobs.

The relation between mortality from female breast cancer and non-farming outdoor employment was most negative in the region of greatest residential sunlight (OR 0.75 (95% CI 0.55 to 1.03)). It remained negative in both physical activity strata (OR 0.90 (low activity) and OR 0.82 (high activity)). Similarly, colon cancer showed a negative association with non-farming outdoor work in the middle and high sunlight regions, which was most pronounced and significant in the highest sunlight region (OR 0.81 (95% CI 0.74 to 0.90)). The association was similarly negative in each physical activity strata.

By contrast, mortality from ovarian cancer was positively, but not significantly, associated with non-farming outdoor jobs in all but the highest sunlight region. It was also increased (OR 1.49; 95% CI 0.86 to 2.58) among those with jobs with low physical activity. Mortality from prostate cancer showed essentially no relation with non-farming outdoor jobs, although the association with farming jobs was increased in the lowest and medium sunlight regions. There was also no association with non-farming outdoor jobs in the two physical activity strata.

DISCUSSION

This study found inverse associations between both residential and occupational exposure to sunlight and mortality from female breast and colon cancer, which were independent of physical activity on the job. Although mortality from ovarian and prostate cancer were inversely associated with residential exposure to sunlight, they were not consistently associated with occupational sunlight. As expected, we also found a positive association between mortality from non-melanoma skin cancer, our positive control cancer, and residential and occupational exposure to sunlight.

This study improved ascertainment of exposure over ecological studies by using individual data on occupation, state of birth and residence at death, socioeconomic status, and physical activity. Although the study also benefited from the many cases in this data set, death certificate studies such as this, have recognised limitations. These include potential misclassification on the underlying cause of death,[28] occupation,[29] and residential exposure, where a lifetime residential history is unavailable, as well as lack of information on other sources of exposure to sunlight, such as leisure activities. Also, death certificates require reliance on crude information such as usual occupation for measures of

Table 3 Odds ratios (95% CIs) for non-melanoma skin, female breast, ovarian, prostate, and colon cancer mortality associated with occupational exposure to sunlight by residential* region and level of physical activity,† adjusted for age, sex, race, socioeconomic status, and physical activity

Occupational exposure to sunlight	Residence: low sunlight OR (95% CI)	Residence: medium sunlight OR (95% CI)	Residence: high sunlight OR (95% CI)	Low physical activity OR (95% CI)	High physical activity
Non-melanoma skin cancer:					
Inside	1.0	1.0	1.0	1.0	1.0
Mixed	1.02 (0.86 to 1.21)	1.03 (0.91 to 1.18)	0.97 (0.82 to 1.14)	0.92 (0.82 to 1.03)	1.03 (0.93 to 1.14)
Outside	1.24 (0.92 to 1.67)	1.41 (1.14 to 1.76)	1.19 (0.91 to 1.54)	1.39 (0.83 to 2.33)	1.25 (1.10 to 1.42)
Farmer	0.84 (0.60 to 1.18)	1.20 (0.97 to 1.49)	1.26 (0.94 to 1.69)	–	1.08 (0.94 to 1.24)
Female breast cancer:					
Inside	1.0	1.0	1.0	1.0	1.0
Mixed	1.05 (0.93 to 1.19)	0.92 (0.83 to 1.03)	1.09 (0.95 to 1.25)	0.90 (0.83 to 0.97)	1.19 (1.09 to 1.30)
Outside	0.94 (0.64 to 1.41)	0.87 (0.65 to 1.17)	0.75 (0.55 to 1.03)	0.90 (0.56 to 1.44)	0.82 (0.69 to 0.98)
Farmer	1.24 (0.83 to 1.86)	0.78 (0.58 to 1.04)	0.90 (0.65 to 1.24)	–	0.89 (0.75 to 1.06)
Ovarian cancer:					
Inside	1.0	1.0	1.0	1.0	1.0
Mixed	0.95 (0.81 to 1.12)	1.03 (0.90 to 1.18)	1.14 (0.96 to 1.36)	0.92 (0.83 to 1.01)	1.16 (1.03 to 1.30)
Outside	1.14 (0.70 to 1.87)	1.17 (0.80 to 1.71)	0.55 (0.33 to 1.91)	1.49 (0.86 to 2.58)	0.87 (0.68 to 1.10)
Farmer	1.36 (0.81 to 2.29)	1.07 (0.72 to 1.61)	1.14 (0.75 to 1.74)	–	1.07 (0.85 to 1.36)
Prostate cancer:					
Inside	1.0	1.0	1.0	1.0	1.0
Mixed	1.03 (0.97 to 1.09)	0.96 (0.91 to 1.00)	1.02 (0.96 to 1.08)	0.98 (0.95 to 1.02)	1.04 (1.01 to 1.08)
Outside	1.04 (0.93 to 1.15)	1.04 (0.96 to 1.14)	0.95 (0.86 to 1.04)	1.02 (0.83 to 1.26)	1.01 (0.97 to 1.06)
Farmer	1.28 (1.16 to 1.42)	1.21 (1.12 to 1.31)	1.01 (0.91 to 1.12)	–	1.18 (1.12 to 1.24)
Colon cancer:					
Inside	1.0	1.0	1.0	1.0	1.0
Mixed	1.01 (0.97 to 1.06)	0.94 (0.90 to 0.98)	1.00 (0.95 to 1.06)	0.94 (0.91 to 0.97)	1.00 (0.97 to 1.04)
Outside	0.99 (0.90 to 1.09)	0.92 (0.85 to 1.00)	0.81 (0.74 to 0.90)	0.92 (0.76 to 1.12)	0.89 (0.85 to 0.93)
Farmer	1.09 (0.99 to 1.21)	1.04 (0.97 to 1.11)	1.06 (0.95 to 1.17)	–	1.01 (0.97 to 1.06)

*Region is as identified in table 1; †low physical activity includes those jobs described as sedentary or involving low physical activity, whereas high physical activity includes those jobs described as involving moderate or high physical activity.

socioeconomic status and physical activity and cannot assess physical activity unrelated to occupation. Thus, there is no independent source of information on socioeconomic status and occupational physical activity and no assessment of recreational physical activity. Furthermore, there is a lack of information on potential confounders, which, for example in the case of breast cancer, includes parity and other reproductive factors, as well as alcohol, diet, and use of oral contraceptives.

Importantly, there is also a potential bias in using deaths rather than population as the study base because exposure patterns among decedents may not reflect those in the total population. However, that skin cancer showed the expected association with exposure to sunlight[1] argues against a substantial study bias. Moreover, socioeconomic status as categorised in this model showed a dose-response relation with the risk of female breast, ovarian, and colon cancer, which is also consistent with the findings of several, although not all, studies.[30–32] On the other hand, we found a similar dose-response relation for socioeconomic status and prostate cancer, although differences in socioeconomic status in other studies have been small.[33] Thus, there may be a socioeconomic bias among decedents compared with incident cases, which could potentially have distorted our associations.

Our most noteworthy results were the decreased risk for female breast and colon cancer among those with non-farming outdoor jobs, particularly in the regions of highest sunlight. The breast cancer findings resemble the recent NHANES I follow up study[15] of risk of breast cancer and both exposure to sunlight and vitamin D intake by John *et al*, which found that several measures of these exposures were associated with a reduced risk of breast cancer in white women. Our study, which relied on cruder exposure data than that used in the NHANES I study, replicated their negative association with residential sunlight, and confirmed it in both white and black women.

Just as we found, John *et al* generally found low or no association with sunlight among women who lived in the region of lowest exposure to sunlight. They also generally found that risk reductions were greatest in the region of highest solar radiation, and intermediate in regions of intermediate exposure. This is consistent with findings that vitamin D is not synthesised in winter in regions of lowest solar radiation in the United States.[34]

Only a few studies have analyzed the risk of breast cancer associated with blood concentrations of vitamin D. Although Janowsky *et al* found no case-control differences in 25(OH)D in blood, they found significant mean differences in 1-α-hydroxyvitamin D3 ($1,25(OH)_2D$) concentrations between cases of breast cancer and controls.[16] By contrast, Hiatt *et al* compared serum concentrations of $1,25(OH)_2D$ before diagnosis among cases of breast cancer and non-cases, and found no association.[11]

Analytical epidemiological data on colon cancer do not include estimates of exposure to sunlight. Although several cohort studies reported negative associations between dietary vitamin D intake and colon or colorectal cancer,[35–37] the few case-control studies have been inconsistent.[8 13 38 39]

Recent experimental studies suggest biological plausibility of a protective effect of vitamin D on cancer, particularly for breast and colon cancer. Most notably, hormonal vitamin D, $1,25(OH)_2D$, has been shown to promote cell differentiation and retard or terminate proliferation of human cancer cells in vitro,[40] including breast[41] and colon cancer cells.[42]

The mechanisms by which $1,25(OH)_2D$ may produce an anticarcinogenic, prodifferentiation effect include inhibition of growth, angiogenesis,[43] and metastasis.[44] Evidence in support of the growth inhibition mechanism has been reported from studies of experimental carcinogenesis in several tumour types. For example, $1,25(OH)_2D$ has been shown to suppress formation of breast tumours after

Main messages

- Although sunlight has been positively associated with non-melanoma skin cancer, ecological studies suggest that sunlight may protect against female breast, ovarian, prostate, and colon cancer.
- A death certificate based case-control study in the United States found negative associations between both residential and occupational exposure to sunlight and mortality from female breast and colon cancer.
- Although mortality from ovarian and prostate cancer were inversely associated with residential exposure to sunlight, they were not consistently associated with occupational sunlight.

Policy implications

- The results of this study warrant additional study of the potentially protective effects of sunlight on cancer, using incident cancer cases with more refined measures of sun exposure for both leisure and work.

induction in rats by both nitrosomethylurea[45] and 7,12-dimethylvbenz[a]antracene.[46] Similarly, formation of colon tumours has been suppressed by $1,25(OH)_2D$ in nude mice implanted with a colon cancer cell line.[47]

As John *et al* note, however, these relations do not establish the biological plausibility of the protective effect of sunlight on cancer. Unlike 25(OH)D, a precursor vitamin D metabolite which is highly correlated with levels of sunlight, serum $1,25(OH)_2D$ concentrations are tightly regulated, and not closely tied to levels of sunlight,[48] at least at high levels of exposure. If sunlight is protective against some cancers by a mechanism involving vitamin D, presumably exposure to sunlight may be linked to the endogenous hormonal vitamin D dose at the tissue level or risk of cancer may be connected to 25(OH)D.

Much remains to be explained about the biology of sunlight and cancer. Although this study is exploratory, with necessarily unrefined sunlight and other exposure categorisations, our findings of significant negative associations between both residential and occupational exposure to sunlight and mortality from female breast and colon cancer warrant additional study. The hypothesis that sunlight may reduce the risk of female breast cancer and colon cancer should be investigated using incident cases with more refined measures of sun exposure for both leisure and work.

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