

To distinguish solarium use with and without risk behavior on melanoma incidence and all- cause mortality. -A report from the large MISS Cohort

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Abstract

Background:

Artificial ultraviolet radiation (UVR) from solarium use has been linked to melanoma in some studies, while others report lower overall mortality. Whether melanoma risk is due to solarium use itself or to associated behaviors indicating intermittent solar overexposure remains unclear.

Methods:

The Melanoma of Southern Sweden (MISS) cohort included ~ 29,000 women enrolled in 1990 and followed for up to 34 years. Solarium use and sun exposure habits were assessed at baseline and after 10 years. Participants were categorized as non-users, solarium users without, or with indicators of intermittent solar overexposure. Cox proportional hazards models estimated hazard ratios (HRs) for melanoma and all-cause mortality. Sensitivity analyses, attributable risk, and restricted mean survival time (RMST) over 25 years were evaluated.

Results:

Solarium use without indicators of solar overexposure was not associated with melanoma risk. Solarium users with overexposure indicators had a higher melanoma risk (HR 1.60, 95% CI 1.30–2.00). Both solarium user groups had ~ 18% lower all-cause mortality than non-users. Approximately one-third of melanomas among solarium users was attributable to solar overexposure. Over 25 years, solarium users had an RMST nearly 10 months longer than non-users.

Conclusions:

Melanoma risk among solarium users appears driven by intermittent solar overexposure rather than solarium use itself, while solarium use was associated with lower all-cause mortality. Our findings indicate that prevention efforts should focus on reducing intermittent UV overexposure behaviors.

1 Introduction

Ultraviolet radiation (UVR) has been recognized as a human carcinogen since 1928 [1]. Consequently, public health efforts have largely focused on reducing UV exposure to lower the risk of skin cancer [2]. However, UVR also appears to exert biological effects that may influence overall health and mortality. Seasonal variations in disease incidence have long been observed, including a 40–50% higher incidence of cardiovascular disease during winter compared with summer. Initially explained by a temperature hypothesis, this concept was challenged in 1981 by Scragg, who proposed that seasonal variation in UV exposure—possibly mediated through vitamin D—might be responsible [3]. This hypothesis stimulated a

large number of observational studies reporting associations between low vitamin D levels and increased morbidity and mortality^[4]. However, randomized controlled trials, meta-analyses, and Mendelian randomization studies have consistently shown little or no benefit of vitamin D supplementation on all-cause mortality in the general population [5, 6]. In contrast to vitamin D supplementation, most large epidemiological studies of sun exposure have demonstrated an inverse association between sun or UVR exposure and total mortality [7–9].

Intermittent UV overexposure has constantly been associated with increased risk of melanoma^[10, 11]. Medical UVB treatment has not been associated with melanoma but has been associated with a lower incidence of cardiovascular events [12, 13]. Oral psoralen UVA (PUVA) treatment has been associated with melanoma in some studies, though not in others [12]. Similarly, solarium use (mainly UVA) has been associated with melanoma in some studies but not consistently across the literature^[14]. In the case of PUVA therapy, melanoma risk appears related to the combination of psoralen and UVA exposure, while solarium users are reported to engage in behaviors associated with intermittent solar overexposure [12]. Thus, the causal relationship between artificial UV exposure from solariums and melanoma remains uncertain, and studies simultaneously assessing both potential harmful and beneficial effects are rare.

The Melanoma of Southern Sweden (MISS) cohort, comprising approximately 29,000 women enrolled in 1990, is well suited to investigate the long-term health effects of solarium use, including both melanoma incidence and all-cause mortality [8] [15]. In the present study, we compare melanoma incidence and all-cause mortality among non-users of solariums and solarium users with and without risk behaviors over a 34-year follow-up period.

By distinguishing the effect of solarium use with and without risk behaviors associated with intermittent solar overexposure, we aim to untangle whether melanoma risk is attributable to solarium use per se or to the accompanying solar overexposure behaviors.

2 Methods

This study was conducted as a prospective cohort study. Participants were enrolled at baseline 1990 and followed from the date of inclusion until the occurrence of the outcome of melanoma, death, censoring, or the end of the follow-up period (1 January 2025), whichever came first. Information on sun exposure habits and solarium use was collected at baseline using questionnaires during 1990 and in the year 2000. Participants were categorized into three exposure groups: no solarium use, solarium use without indicators of intermittent solar overexposure, and with indicators of intermittent solar overexposure. Indicators of intermittent solar overexposure were defined as at least one of self-reported use of sunscreen to enable prolonged sunbathing, sunburn related to sun exposure, or traveling south at least one week per year for sunbathing.

Two outcomes were investigated: 1. Incident melanoma, defined as the first recorded diagnosis of cutaneous malignant melanoma (MM) during the 34-year follow-up. 2. All-cause mortality, defined as

death from any cause during follow-up.

Age was used as the underlying time scale in all analyses. Participants entered the risk set at their age at baseline and were followed until age at melanoma diagnosis (for melanoma analyses), age at death, or age at censoring due to emigration or end of follow-up, whichever occurred first. Age was chosen as the time scale because it is a strong determinant of both melanoma incidence and mortality, and using age as the underlying time axis allows for a more precise and flexible control of age-related risk than conventional adjustment for baseline age. Lifestyle factors such as physical activity and BMI were considered primarily as potential confounders for all-cause mortality and were therefore included in descriptive analyses and mortality models. A dummy variable, “comorbidity,” was created to identify women who had received treatment with antidiabetic drugs [Anatomical Therapeutic Chemical Classification System (ATC) code A10] or anticoagulants (ATC B01) or medications for cardiovascular disease (ATC C01–C10) for a duration exceeding one month.

We present in Table 2a Model 1 as crude models with age as the time scale. Model 2, which is our primary model, assessed risk of melanoma and was adjusted for factors known to be associated with melanoma such as red hair and/or freckles, more than 4 raised nevi on the left arm, sunburn during childhood or youth, and first-degree family history of melanoma. In Model 3, the above factors were additionally adjusted for education, family income, smoking, and marital status. Since age was used as the time scale, no additional adjustment for age was included in the models.

In Table 2b we present similar models for all-cause mortality, with model 3 as the principal fully adjusted model which also included BMI and exercise.

2.1 Statistical Analysis

Associations between no solarium use, solarium use without risk behaviors and solarium use with risk behaviors (increased probability of overexposure), and the outcomes were assessed using Cox proportional hazards regression models to estimate hazard ratios (HRs) and 95% confidence intervals (CI) for melanoma risk and all-cause mortality. Age was used as the underlying time scale. The proportional hazards assumption was assessed through inspection of effect stability across follow-up time and sensitivity analyses with delayed entry and exclusion of early follow-up. No evidence of meaningful non-proportionality was observed. To complement relative risk estimates from Cox proportional hazards models, an absolute measure of survival was estimated using restricted mean survival time (RMST). RMST was calculated as the area under the Kaplan–Meier survival curves up to 25 years of follow-up. Survival curves were estimated using time since inclusion as the time scale, and RMST was computed separately for solarium users and non-users. The difference in RMST between groups was used to express absolute differences in survival time over the restricted follow-up period.

Several sensitivity analyses were conducted to assess the robustness of the findings and to address potential sources of bias. First, to evaluate the impact of potential changes in solarium use over time, follow-up was censored at 10 years after inclusion, corresponding to the time point when updated

information on solarium habits was available for a subset of participants. Second, to reduce the potential influence of reverse causation, analyses were repeated after excluding women with comorbidity. Third, to further address possible reverse causation and preclinical disease influencing exposure behavior, analyses were conducted excluding the first 5 years of follow-up. All sensitivity analyses used Cox proportional hazards models with age as the underlying time scale and delayed entry at age at inclusion.

The attributable fraction of overexposure among solarium users was estimated using the adjusted hazard ratios from Cox regression models, assuming a causal interpretation of the association between UV overexposure and melanoma risk ($(HR_{risk} - HR_{no_risk}) / HR_{risk}$) and expressed as a percentage). All statistical analyses were performed using IBM SPSS software version 26. Figures were created using Python. *P*-values < 0.05 were considered significant.

3 Results

In Table 1 we present characteristics of the study population by categorized solarium use; no solarium, solarium without risk behavior or solarium use with indicators of risk behavior (intermittent solar overexposure). We can see that solarium users were younger, wealthier, had lower BMI, were more physically active, had less comorbidity, and reported greater sun exposure habits. There were minor differences regarding known melanoma risk factors, except that solarium users more frequently had fair skin. In Fig. 1 we show fully adjusted HR of melanoma and all-cause mortality by solarium use.

Table 2a and Fig. 2 shows the main results for melanoma incidence. Women who reported no solarium use and women who used solarium without risk behavior had similar melanoma risk, whereas solarium users with risk behavior had a 60% higher risk (HR 1.60, 95% CI 1.30–2.00). Estimates were similar after censoring follow-up at five years (HR 1.10, 95% CI 0.90–1.34 for solarium use without risk behavior, and HR 1.65, 95% CI 1.33–2.04 for solarium use with risk behavior) and after exclusion of women with comorbidity at baseline (HR 1.08, 95% CI 0.88–1.32 and HR 1.62, 95% CI 1.31–2.01, respectively). When analyses were restricted to women who responded to the second questionnaire and updated information on solarium use (approximately in 2001), effect estimates for melanoma were slightly higher (HR 1.14, 95% CI 0.89–1.47 and HR 1.96, 95% CI 1.54–2.49, respectively). Under a causal assumption, the attributable fraction of melanoma risk due to solar overexposure among solarium users was estimated to be 33%, calculated as $(1.60 - 1.07) / 1.60$.

Table 2b and Fig. 2 shows the main results for all-cause mortality. Compared with women who reported no solarium use, solarium users without and with risk behavior had an approximately 18% lower risk of all-cause mortality (HR 0.83, 95% CI 0.77–0.88 and HR 0.81, 95% CI 0.76–0.87, respectively). To provide an absolute measure of this association, restricted mean survival time over 25 years of follow-up was estimated. Restricted mean survival was 23.96 years among solarium users and 23.12 years among non-users, corresponding to an absolute difference of approximately 10 months. When analyses were restricted to women who responded to the second questionnaire and updated solarium use, effect

estimates were similar to those of the main analysis (HR 0.83, 95% CI 0.77–0.90 and HR 0.83, 95% CI 0.75–0.91, respectively).

Table S1 presents the crude estimates for the individual indicators of intermittent solar overexposure. The associations were generally consistent in direction and size, supporting their use as a composite exposure. The composite exposure comprised three behaviors reflecting higher probability of intermittent solar overexposure.

4 Discussion

4.1 Main Results

Compared with participants who did not use solarium, those reporting solarium use with indicators of UV overexposure had a significantly increased risk of melanoma, whereas no clear association was observed among solarium users without indicators of intermittent solar overexposure. In addition, both groups of solarium users were at a significantly approximately 18% reduced risk of all-cause mortality compared with non-users of solarium during the 34-year follow-up. Thus, intermittent solar overexposure did not additionally improve all-cause mortality but increased melanoma risk. The associations between solarium use and both melanoma and all-cause mortality risk were robust across multiple sensitivity analyses, with hazard ratios of similar magnitude and direction in all models. Thus, adjustment for known confounders changed effect estimates only modestly.

Among participants reporting solarium use, an estimated 33% of melanoma cases were attributable to behaviors indicative of intermittent solar overexposure. These estimates of attributable fraction should be interpreted as indicative of the potential proportion of melanoma cases among solarium users that might be preventable by avoiding exposure practices associated with intermittent solar overexposure, rather than as definitive causal effects.

In addition to relative hazard ratios, we estimated restricted mean survival time to provide an absolute measure of the association between solarium use and all-cause mortality. Over 25 years of follow-up, solarium users had an approximately 10-month longer restricted mean survival compared with non-users, or one year during the 34-year follow-up. This absolute difference illustrates that the observed 18% lower hazard of death corresponds to a difference in survival time at the population level. As with the relative estimates, this finding should be interpreted cautiously, as residual confounding and lifestyle-related factors associated with solarium use may partly explain the observed difference rather than a causal protective effect.

4.2 Relation to other findings

In line with our findings there is an emerging body of observational evidence that UV exposure is not only related to an increased risk of skin cancer, but also a reduced rate of cancer mortality and all-cause mortality [7–9]. In agreement with this, it has been suggested that the International Agency for Research

on Cancer (IARC) classification should be refined to state that excessive UVR exposure, rather than UVR per se, constitutes a Group 1 human carcinogen [16]. Our main conclusions in line with the recent World Health Organization's recommendations—"avoid too much sun exposure"—, but not in accordance to their recommendation to "never use sun beds" [17]. However, the recent European Code Against Cancer 5 (ECAC5) state a more nuanced message, that "solar UVR, and to a lesser extent, artificial UVR exposure are major causes of skin cancer" [18]. In this paper we differentiated solarium use against solarium use with solar overexposure. We did not assess any difference between moderate solarium use and solarium overexposure.

Consistent with our findings, other studies have reported solarium users to be younger, smokers, better educated, to have more nevi, fair skin, and to use more alcohol [19, 20].

4.3 Strength and Limitations

The consistency of results across cause-specific Cox models and multiple sensitivity analyses supports the robustness of the findings. The use of age as the underlying time scale and the broad adjustment for known and potential risk factors represent important methodological strengths. A further strength is that our HR for solarium use and melanoma incidence, 1.28, 95% CI 1.09–1.51, without adjustment for solar risk behavior, was almost identical to that reported in the recent ECAC5 report (1.27, 95% CI 1.16–1.39) [18]. HRs should nevertheless be interpreted cautiously. Although sensitivity analyses reduced the likelihood of reverse causation, changes in exposure over time, and healthy user bias, the observed lower all-cause mortality among indoor solarium users may still be influenced by residual confounding rather than reflecting a causal protective effect of solarium use.

Long-term cohort studies examining the nuanced effects of UV exposure remain underfunded compared with studies focusing only on risk amplification. This imbalance may contribute to a structural publication bias, where some research questions are more frequently tested and disseminated than others.

Solarium use and sun exposure habits were self-reported and assessed at discrete time points, which may have resulted in some exposure misclassification. However, analyses that censored follow-up and restricted the sample to participants with updated exposure information yielded similar results, suggesting that such misclassification is unlikely to fully explain the findings. Because we included only women aged 25 years and older, our results cannot be generalized to younger women.

Previous studies have reported associations between UV exposure and hormonal and behavioral factors, including reproductive hormones and sexual activity, which may partly contribute to the observed mortality differences [21]. These factors could not be accounted for in the present analyses.

In this study, we sought to distinguish between solarium UV exposure and solar UV-related behavior. By categorizing all solarium use as dangerous, important harmful sun behaviors—which might represent the true risk factors—could be overlooked.

5 Conclusions

Our findings indicate that solarium use per se was not associated with an increased risk of melanoma; instead, the excess risk observed among solarium users appeared to be attributable to behaviors indicative of intermittent solar overexposure. At the same time, solarium users exhibited lower all-cause mortality, underscoring that different patterns of UV exposure may be associated with divergent health outcomes. Taken together, these findings suggest that preventive efforts should prioritize reducing intermittent solar UV overexposure rather than targeting solarium use per se.

Declarations

Competing interest

The authors report no competing interests

Ethical approval

The study was approved by the Ethics Committee of Lund University (LU 632-03) and later amendments

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Author Contribution

PL prepared the Original draft of the manuscript and analysis. ELE prepared figures in Python. All authors reviewed, edited, and approved the final manuscript.

Data Availability

We do not have ethical permission to share data

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Tables

Table 1 Characteristics of study population according to categorized solarium use

			Solarium use			
			No solarium use		Solarium use	
					Solarium use	
					No risk behaviour	
					Risk behaviour	
Demographics						
Age at inclusion	48.9	11.8	42.6	11.0	42.1	11.2
Education						
≤9 years	3783	23.7%	1169	13.4%	631	13.0%
9 years	1599	10.0%	741	8.5%	433	8.9%
10-12 years	3442	21.6%	2692	30.9%	1525	31.3%
≥12 years	5069	31.8%	2980	34.2%	1648	33.8%
other	2049	12.9%	1124	12.9%	633	13.0%
Marital status						
Married	12618	79.1%	6670	76.6%	3722	76.4%
Family income						
Low	4402	27.6%	1334	15.3%	712	14.6%
middle	4599	28.8%	2827	32.5%	1487	30.5%
High	6941	43.5%	4545	52.2%	2671	54.8%
Smoking						
	5064	31.8%	3823	43.9%	2212	45.4%
BMI						
<25	6470	40.6%	4040	46.4%	2573	52.8%
25-30	3673	23.0%	1952	22.4%	1155	23.7%
>30	1561	9.8%	585	6.7%	332	6.8%
?	4238	26.6%	2129	24.5%	810	16.6%
Exercise						
low	3092	19.4%	1745	20.0%	583	12.0%
Moderate	6824	42.8%	3811	43.8%	2230	45.8%

Active	3631	22.8%	2454	28.2%	1615	33.2%
?	2395	15.0%	696	8.0%	442	9.1%

Melanoma risk factors

Red hair and/or Freckles	6397	40.1%	3917	45.0%	2222	45.6%
Number of raised navi left arm >4	141	0.9%	84	1.0%	38	0.8%
Heredity of melanoma	623	3.9%	350	4.0%	159	3.3%
Sunburn Childhood	5086	31.9%	2989	34.3%	1817	37.3%
Sunburn Youth	7308	45.8%	4436	51.0%	2644	54.3%

Sun exposure habits

Sunbathing Winter vaccation	1853	11.6%	2082	23.9%	1518	31.2%
Sunbathing Summer	14006	87.9%	8548	98.2%	4820	99.0%
Comorbidity at inception	2003	12.6%	589	6.8%	330	6.8%

Number and percentage or mean and standard deviations (SD) are given

Risk behavior was defined as a measure of solar overexposure i.e. at least one of ,

burn when sun exposing, use of sunscreen to enable prolonged sunbathing, and traveling

south at least one week a year

Heredity = First degree heredity, Red hair and/or freckles as a measure of type 1 skin

Number of navi = number of raised nevi on left arm

Comorbidity defined as having recieved antidiabetics, antikoagulants or cardiovascular

medication more than one month

Table 2a Hazard ratios (HR) was calculated using Coxregression with age as the time scale on the risk of incident melanoma by a categorized solarium variable

	MM / no MM		Crude model		Model 2		Model 3	
		MM%	HR	95% CI	HR	95% CI	HR	95% CI
Solarium Use								
No solarium use	285/15657	1.8%	1.0	ref	1.0	ref	1.0	ref
Yes, no overexposure	169/8537	1.9%	1.07	0.9–1.3	1.07	0.9–1.30	1.05	0.9–1.3
Yes, Overexposure	141/4729	2.9%	1.60	1.3–2.0	1.60	1.30–2.00	1.56	1.3–1.9

Table 2b HR with Cox regression with age as the time scale on the risk of all-cause mortality by a categorized solarium variable

	death / no deaths		Crude model		Model 2		Model 3	
		death%	HR	95% CI	HR	95% CI	HR	95% CI
Solarium USE								
No solarium use	6320/9622	39.6%	1.0	ref	1.0	ref	1.0	ref
Yes, no overexposure	1886/6820	21.7%	0.84	0.80–0.89	0.85	0.80–0.89	0.83	0.79–0.88
Yes, Overexposure	996/3874	20.5%	0.82	0.77–0.88	0.83	0.77–0.88	0.81	0.76–0.87

MM = Cutaneous malignant melanoma, 95% CI = 95% confidence interval

Overexposure was defined as sun exposure habits with increased risk of intermittent solar overexposure, i.e., at least one of the following three; burning while sunexposure, using sun blockers to enable prolonged sunbathing, or going abroad south to sunbath at least one week per year

Crude model, Cox regression with age as the time scale

Model 2: Cox regression as above and adjusted for red hair/freckles, first degree heritage of MM, more than raised 4 nevi, more than two sunburn per year during childhood or youth. Regarded as the primary analysis regarding risk of MM

Model 3: above and marital status, smoking, family income, and education

Regarding risk of all-cause mortality, in model 3 BMI and exercise level was also included and this was considered the primary analysis in modelling the risk of all-cause mortality

Figures

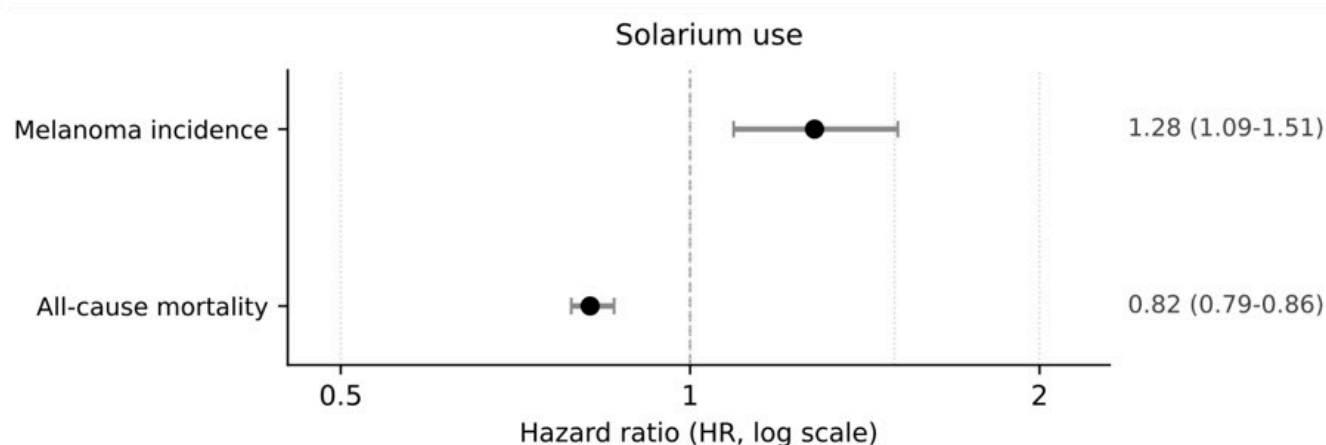


Figure 1

Hazard ratios for melanoma incidence and all-cause mortality according to solarium use

Figure 1. Hazard ratios (HRs) and 95% confidence intervals (CIs) for melanoma incidence and all-cause mortality according to solarium use estimates are derived from Cox proportional hazards models with age as the underlying time scale and adjusted for established melanoma risk factors and socioeconomic and lifestyle variables as described in the Methods. The vertical dashed line indicates HR = 1.0.

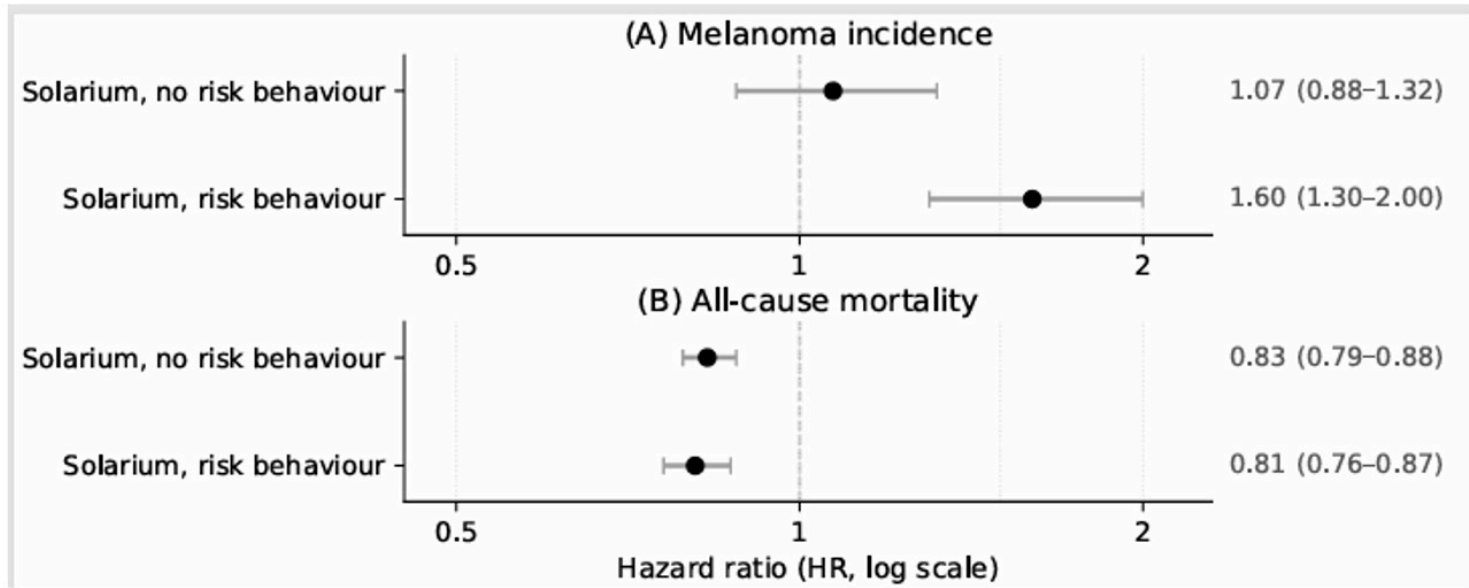


Figure 2

Hazard ratios for melanoma incidence and all-cause mortality according to categorized solarium use

Figure 2. Hazard ratios (HRs) and 95% confidence intervals (CIs) for **(A)** melanoma incidence and **(B)** all-cause mortality according to solarium use, categorized as no solarium use (reference), solarium use without indicators of intermittent solar overexposure, and solarium use with indicators of intermittent solar overexposure. Estimates are derived from Cox proportional hazards models with age as the underlying time scale and adjusted for established melanoma risk factors and socioeconomic and lifestyle variables as described in the Methods. The vertical dashed line indicates HR = 1.0.

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