**How many melanomas might be prevented if more people applied sunscreen regularly?**

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**conflicts of interest**

The authors have no conflicts to declare.

**What’s already known about this topic?**

* Sunscreen prevents sunburn and protects skin cells (including melanocytes) from mutations induced by ultraviolet radiation.
* Prospective cohort studies and one randomised trial suggest regular sunscreen use reduces risk of melanoma.
* Regular use of sunscreen is uncommon, even in populations residing in areas of high ambient sunlight levels.

**What does this study add?**

* Under plausible scenarios of increasing prevalence of sunscreen use, cumulative incidence of melanoma between 2012-2031 could reduce by ~10% in high-incidence populations.
* Monitoring sunscreen use in populations is necessary to inform melanoma control efforts.

**SUMMARY**

**Background:** Ultraviolet radiation causes cutaneous melanoma. Sunscreen prevents sunburn and protects skin cells against mutations. High-quality epidemiological studies suggest regular sunscreen use prevents melanoma.

**Objective:** To calculate the potential impact fraction (PIF) for melanoma in the United States (US) and Australia assuming a range of different intervention scenarios intended to increase sunscreen use.

**Methods:** We calculated the PIF, the proportional difference between the observed number of melanomas arising under prevailing levels of sunscreen use compared with the number expected under counter-factual scenarios. We used published melanoma incidence projections for US Whites and Australia from 2012 through 2031 as the baseline condition, with estimates for protective effects of ‘regular sunscreen use’ from the literature. Sunscreen prevalence was sourced from national or state surveys.

**Results:** Under a plausible public-health intervention scenario comprising incremental increases in sunscreen prevalence over a 10-year implementation program, we estimated that cumulatively to 2031, 231,053 fewer melanomas would arise in the US white population (PIF 11%) and 28,071 fewer melanomas would arise in Australia (PIF 10%). Under the theoretical maximum model of sunscreen use, almost 797,000 (PIF 38%) and 96,000 (PIF 34%) melanomas would be prevented in the US and Australia respectively between 2012-2031. A sensitivity analysis using weaker effect estimates resulted in more conservative PIF estimates.

**Conclusions:** Overall, interventions to increase use of sunscreen would result in moderate reductions in melanoma incidence, assuming no compensatory over-exposure to the sun. Countries with a high incidence of melanoma should monitor levels of sunscreen use in the community.

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**Abbreviations**

RCT Randomised controlled trial

UVR Ultraviolet radiation

UVB Ultraviolet-B

RR Relative risk

HR Hazard ratio

SPF Sun-protection factor

MED Minimal erythemal dose

PIF Potential impact fraction

US United States

NSW New South Wales

CPD Cyclobutane pyrimidine dimers

**INTRODUCTION**

Ultraviolet radiation (UVR) from sunlight is the main environmental cause of cutaneous melanoma,1, 2 and it has been estimated that between 63% and 90% of melanoma cases are directly attributable to this exposure.3, 4 With melanoma incidence still increasing in most susceptible populations globally,5, 6 there is great potential to reduce this public health burden. While the mechanisms by which UVR causes melanoma have not yet been fully characterised, consensus opinion is that wavelengths in the UVB range (290-320 nm) are most likely the main contributors, through pyrimidine dimer and 6-4 photoproduct formation.7 Recent experiments, however, have demonstrated the mutagenic effects of wavelengths in the UVA range (320-400 nm), whereby UVA-induced reactive oxygen and nitrogen species combine to excite electrons in melanin pigments.8 These observations have led to renewed concerns that UVA may contribute more to melanomagenesis than was previously believed. Sunscreens labelled “broad spectrum” provide protection from both UVB and UVA.9

 Converging lines of evidence provide strong grounds for inferring that sunscreen applied to human skin prior to UVR exposure reduces the risk of melanoma: (1) most cutaneous melanomas harbour UVR-induced driver mutations in key genes;7, 10-13 (2) under experimental conditions, sunscreens applied to human skin before UVR exposure prevent essentially all molecular sequelae of subsequent exposure in epidermal cells, including melanocytes;14 (3) sunscreen prevents or retards melanoma development in UVR-dependent mouse models15 and (4) in the only randomised trial to test the hypothesis that regular sunscreen use prevents melanoma, participants assigned to ‘daily sunscreen’ had lower incidence of melanoma than those assigned to ‘discretionary use’.16

Epidemiologic investigations on the association between sunscreen use and melanoma have, however, yielded inconsistent findings. Several systematic reviews have explored the potential cancer preventive properties of sunscreen17-19 but all were restricted to observational epidemiologic studies, which are prone to several potentially severe biases, including confounding-by-indication,20 and for case-control studies, recall bias. Overall, these reviews reported heterogeneous findings from observational studies, with some studies reporting inverse associations between sunscreen use and melanoma, while others report positive associations in which people who report regularly using sunscreen have higher risks of melanoma. While all observational studies face challenges with confounding-by-indication, prospective studies are less prone to various reporting biases (especially recall bias) than case-control studies. Two population-based prospective studies have examined the association between sunscreen use and melanoma, one reporting no association for ever use (no HR reported),21 and the other reporting a significant protective effect (HR 0.67; 95% CI 0.53-0.83).22

Only randomised controlled trials, in which people are allocated to treatment groups at random, can adequately assess the association with minimal risk of bias. The only randomised controlled trial examining the effect of regular sunscreen use on skin cancer was conducted in Nambour (Queensland, Australia). That trial found that adults aged 25-75 years randomised to apply daily sunscreen had a borderline significant halving of incident melanomas16 compared with those randomised to discretionary sunscreen use. After 10 years of post-trial follow-up, 11 primary melanomas were identified in the regular sunscreen group, and 22 in the discretionary group (RR 0.50; 95% CI 0.24-1.02).

Thus, the level 1b (single RCT) and 2b (individual cohort study) evidence suggests that regular use of sunscreen reduces the risks of cutaneous melanoma. Accordingly, clinical practice recommendations on sun protection reflect the consensus guidelines of numerous medical/cancer prevention authorities as well as expert opinion.23 The American Academy of Dermatology (AAD),24 the US Surgeon General,25 the Centers for Disease Control and Prevention (CDC),26 the Food and Drug Administration (FDA),27 the American Cancer Society (ACS),28 Cancer Council Australia (CCA),29 Cancer Research UK30 and the British Association of Dermatologists (BAD)31 all recommend the use of broad spectrum sunscreen with a sun protection factor (SPF) of at least 15 (30+ for AAD, CCA, ACS and BAD) as a component of a comprehensive sun protection program. Adherence to these guidelines, however, remains suboptimal.

Given the global consensus in position statements from leading cancer prevention organisations, we sought to estimate the likely impact on melanoma incidence under the assumption that greater numbers of people heeded that advice. We chose two populations for comparison, based upon the availability of recent data on the prevalence of regular sunscreen use, the United States (US) and Australia.

**METHODS**

The population impact fraction (PIF)32 is the proportional difference between the observed number of melanoma cases under prevailing levels of sunscreen use and the number expected under alternative scenarios of higher prevalence of sunscreen use. We used the PREVENT Plus (V. 3.01) software package to estimate numbers of potentially preventable melanomas in Australia and the US under various scenarios.33 (We also sought relevant data for other populations, including the UK, but were unable to locate sufficiently representative and recent data for sunscreen prevalence.) The model integrates estimates of the prevalence of sunscreen use at base year, changes in prevalence at subsequent time points under different intervention scenarios, and estimates for the protective effect of sunscreen (expressed as a relative risk) to generate future estimates of melanoma incidence under the stated scenarios. Specifically, the model compares the projected future incidence of melanoma without interventions (baseline or ‘no change’ scenario) with the projected future incidence after implementing interventions to increase the prevalence of sunscreen use (see ‘Intervention Scenarios’). We assumed that the effect of sunscreen was immediate, and that it took 10 years for melanoma risks among non-users to decline to those of regular users.

*Prevalence of sunscreen use and relative risks of melanoma:*

For the US we used sunscreen prevalence data for non-Hispanic white adults aged 20-59 years from the National Health and Nutrition Examination Survey (NHANES) 2009-2012 (n=14,463).34 In that survey, 6% of men and 22% of women reported ‘always’ using sunscreen. For US white children we used the 43% prevalence of use "when going outdoors in summer” estimated from a cross-sectional telephone survey of white youth aged 11-18 years (n=1380) conducted in 2004.35 For Australia, we used population-based prevalence estimates for regular sunscreen use in Australian adults aged 16 years and over from the 2010 New South Wales (NSW) Population Health Survey;36 21% of men and 35% of women reported ‘always’ applying a broad-spectrum sunscreen (sun-protection factor (SPF) 15+) to exposed skin when in the sun for more than 15 minutes in summer. These prevalence estimates were applied to adults aged 17 years and over. For Australian children, prevalence estimates were sourced from the NSW School Students Health Behaviours Survey.37 In 12-15 year olds, prevalence of “maximum protection sunscreen (SPF 30+)” use when outside for an hour or more between 11am and 3pm in summer was 39% in boys and 51% in girls; and for 16-17 year olds it was 31% for boys and 48% for girls. The prevalence in 12-15 year olds was applied to 0-12 year olds in our modelling. We used the RR for a protective effect of sunscreen from the long-term follow-up of the Nambour Skin Cancer Prevention Trial.16 In a sensitivity analysis, we used the hazard ratio (HR) for use of sunscreen (SPF 15+) on at least one occasion (0.67, 95% CI 0.53-0.87) from the Norwegian Women and Cancer Study.22 The only other prospective cohort to examine the association between sunscreen use and melanoma, the Nurses’ Health Study, did not present an estimate of effect.21

*Melanoma incidence data and population projections:*

We used published melanoma incidence projections for US Whites and Australia from 2012 through to 2031, full methods for which have been published.6 We used cancer registry data on melanoma incidence for the period 1982-2011, and applied modified age-period cohort models to project incidence rates and number of melanomas out to 2031 using NORDPRED.38

*Intervention scenarios:*

To estimate the incidence reduction from a plausible public-health intervention we postulated the scenario in which the prevalence of sunscreen use increased from baseline by 5% per year over a 10-year period (partial uptake, 10-year implementation; Model 1). We also modelled the theoretical maximum incidence reduction possible through a sunscreen intervention, in which 100% of the population used sunscreen daily (i.e. all age-groups) with immediate implementation from year 1 (2012) of the intervention (theoretical maximum; Model 2) (Table 1). A ‘delayed maximum uptake’ scenario assumed 100% sunscreen use for all people but with a ten-year implementation period (full uptake, delayed implementation; Model 3). We repeated the ‘partial uptake, 10-year implementation’ (Model 1) scenario for people aged under 75 years only (Model 4), and we also examined the effect of the timing of the interventions (school age, working age and pre-retirement age, Models 5-7 respectively), under the assumption that the protective effect of sunscreen is constant across all age-groups. The interventions were assumed to have been applied from the year 2012, the first year of our projected incidence rates.

This study comprised an ecological analysis of publicly available data; hence no institutional ethical review was required.

**RESULTS**

Under a realistic intervention scenario which modelled a 5% per year increase in sunscreen use across the whole population from 2012 to 2022 (partial uptake, 10-year implementation; Model 1) (Table 1), we estimated that cumulatively to 2031, 231,053 fewer melanomas would arise in the US white population (PIF 11%) and 28,071 fewer melanomas would arise in Australia (PIF 10%). Under the ‘theoretical maximum’ scenario, if 100% of the population used sunscreen regularly from 2012 onwards (full-uptake, immediate implementation; Model 2) (Table 1), then cumulative melanoma incidence to 2031 would be 38% lower for US whites and 34% lower for Australia (equating to cumulative totals of 796,872 and 96,417 prevented melanoma cases, respectively) (Table 2; Figure 1). In the 20-year projection period to 2031, interventions in older adults had a greater impact on melanoma incidence than those targeting school-age children (i.e. when the oldest in the childhood target group would only be reaching their late 30s) (Table 2; Figure S1).

We conducted a sensitivity analysis using the more conservative effect estimate from the large population-based Norwegian cohort study.[22](#_ENREF_22) Using this estimate, under the ‘partial uptake, 10-year implementation’ scenario (Model 1) we estimated that cumulatively to 2031, 142,979 fewer melanomas would arise in the US white population (PIF 7%) and 17,520 fewer melanomas would arise in Australia (PIF 6%) (Table S1; Figure S2). The ‘theoretical maximum’ scenario (Model 2) resulted in estimates of melanoma incidence 24% lower for US whites and 21% lower for Australia. The interventions in different age-groups showed similar trends to our primary analyses using the effect estimate from the Nambour Trial,[16](#_ENREF_16) albeit with lower estimates of prevented melanomas (Table S1, Figure S3).

**DISCUSSION**

We modelled the potential impact of different scenarios of sunscreen use on future melanoma incidence in two populations with high rates of melanoma, namely US Whites and Australia. Our ‘theoretical maximum’ impact scenario (full uptake, immediate implementation; Model 2) estimated reductions of up to 38% and 34% of melanomas projected cumulatively to the year 2031 in the US and Australia respectively. Some may be surprised that even a universal sunscreen strategy would reduce cumulative melanoma incidence only by one-third. This finding reflects the fact that, even in randomised trial settings, interventions prescribing daily sunscreen use do not confer complete protection due to less-than-perfect adherence and the fact that even high SPF sunscreens do not completely block all UVR. In other words, the Nambour sunscreen intervention trial observed that the incidence of melanoma was 50% lower in the intervention group (daily application of sunscreen) than in the control group (discretionary use of sunscreen). The implication is that 50% of melanomas will continue to arise despite ‘best practice’ sunscreen use. These findings underscore the need for multi-component interventions targeting multiple sun-protection strategies (as reviewed by the US Surgeon General’s Call to Action to Prevent Skin Cancer[25](#_ENREF_25)).

The most effective sunscreen interventions in the short-term were those aimed at older adults since the burden of melanoma incidence is highest in these age-groups.[6](#_ENREF_6) For example, melanoma rates in 60-79 year olds are expected to be 96/100,000 in US whites by the year 2031 but only 13/100,000 in 20-39 year-olds.[6](#_ENREF_6) Thus, in the short-to-medium term, sunscreen interventions which target older age groups (i.e. with higher age-specific melanoma rates) would likely yield larger reductions in incidence than interventions targeting younger age groups, assuming that the benefits of sunscreen have an immediate and equal effect in all age groups. For that reason, the school age intervention led to much more modest reductions in incidence in the time frame that we examined (i.e. through to 2031). We would anticipate increasing benefits of a school-age intervention after longer duration of follow-up, but this would require models extending out beyond 50 years and based on untestable assumptions about the size, age and sex-structure and rate of change of the underlying population as well as the possible trajectories of melanoma incidence into the future by age-group and birth-cohort.[25](#_ENREF_25) Notwithstanding these considerable barriers, we very cautiously examined the possible effects of a school-age intervention, in Australia, with a 70-year follow-up. We assumed that previously reported melanoma incidence trends (1982-2011) continue to the year 2031,[6](#_ENREF_6) and then remain stable thereafter for the period 2032-2081. We then plotted the ‘base case’ scenario assuming no change in the prevalence of sunscreen use and the ‘school age intervention’ on the same plot (Figure 2). We estimated that by 2081, the school-age intervention would yield a cumulative reduction in melanoma incidence of 20%. Although these calculations are crude, they demonstrate the extremely long timelines required for school-age interventions to lead to sizable reductions in total melanoma incidence. This is entirely predictable, since the birth cohorts subject to the intervention take decades to reach older age and develop melanoma at sufficiently high incidence that differences can be detected between those exposed and not exposed to the sunscreen intervention. Given that sun exposure in early life may be particularly important in melanoma development,[39](#_ENREF_39) it remains possible that the benefits of regular sunscreen use may be greater in young people than we have assumed, potentially leading to greater reductions in melanoma incidence than we have estimated here. We are not aware of any published data reporting age-specific effects of sunscreen use on future risk of melanoma, however we note that the Nambour trial intervened on adults aged 25-75 years and observed a protective effect, indicating that adult-onset sunscreen interventions are beneficial in reducing melanoma incidence.

For our calculations of the PIF we used as the highest-level evidence the risk estimate reported by the only RCT to examine the effect of regular sunscreen use on melanoma (RR 0.50).[16](#_ENREF_16) The trial closely monitored sunscreen use, had high levels of adherence, high rates of follow-up and pathology documentation of all melanoma endpoints independent of knowledge of sunscreen allocation. The risk estimate from the trial was derived from an ‘intention to treat’ analysis which incorporated the effects of incomplete adherence, dropouts and other factors that attenuate the magnitude of the observed association. However, several limitations of the trial have been noted including the relatively small sample size, low number of melanoma events and the observation that the protective effect was seen for melanomas occurring on both sunscreen-intervention and non-intervention body sites. Because of concerns that the effect size from one small trial might be extreme, we conducted a sensitivity analysis using the effect estimate from the Norwegian cohort study[22](#_ENREF_22) (N=143,844; mean follow-up 10.7 years; N=543 melanoma events), yielding more conservative impact fractions. This estimate, however, was based on a time-dependent analysis of sunscreen use defined as “sunscreen SPF ≥15 on one or more occasion” compared with the reference group “consistent use of SPF <15”.[22](#_ENREF_22)

*A priori*, we did not use risk estimates from case-control studies (or meta-analyses of case-control studies) for this analysis because of the dual concerns of confounding-by-indication and, separately, recall bias, which are intractable for case-control studies of melanoma. (Confounding by indication may also affect cohort studies, and if operative, would bias effect estimates towards a positive association between use of sunscreen and melanoma.)

We are aware of only one other study that has evaluated the impact of interventions to limit exposure to UVR on melanoma incidence. DeVries et al.[40](#_ENREF_40) modelled the potential of several scenarios intended to prevent melanoma in four European countries (Finland, Malta, the Netherlands and Scotland) using a similar method incorporating age-specific relative risks and prevalence estimates. Their scenarios did not incorporate sunscreen use, but rather increased “protection” from UVR in occupational and recreational settings, a reduction in use of sunbeds, and a reduction in childhood sunburns. In general, de Vries et al. reported that interventions aimed at protecting people during outdoor work and outdoor hobbies combined with interventions to prevent sunbed use and sunburns in childhood were the most effective, resulting in PIFs ranging from 14-20% cumulatively to the year 2050.

Some of the interventions that we modelled are clearly not achievable in practice (e.g. the ‘theoretical maximum’ scenario of full uptake of sunscreen with immediate implementation from 2012). We have, however, presented a number of alternative scenarios that describe the full range of effects on future melanoma incidence which might be achieved in theory. Our estimates are based on a number of assumptions including the representativeness of the prevalence estimates, the size of the protective effect, a presumption of constancy of effect across all age-groups, and the projected incidence rates. In addition, concerns have been expressed that exhorting people to use sunscreen might lead them to increase their exposure to the sun and thereby (paradoxically) increase their risks of melanoma,[41](#_ENREF_41) although evidence suggests this is the case only when sun exposure is intentional, and not when it is unintentional.[42](#_ENREF_42)

Our choice of study populations was based on the availability of recent nationally representative data on the prevalence of sunscreen use; such data was unavailable for the United Kingdom. This underscores the need for health authorities to monitor levels of sunscreen use (as well as other sun protection measures) in countries where melanoma is a concern.

In summary, sunscreens, designed to protect human skin against the burning effects of acute sun exposure, also decrease the amount of UVR damage to epidermal cells and while randomised trial data is less abundant than we would like, the totality of evidence strongly suggests that people who use sunscreen regularly enjoy some protection from melanoma.[23](#_ENREF_23) While melanoma incidence is the focus of this report, the impact of future sunscreen would go beyond melanoma reduction, and increase the even more substantial burdens of actinic keratoses and cutaneous squamous cell carcinomas. Assuming no ‘compensatory sun exposure’ among people using sunscreen, then interventions designed to increase the proportion of people who use sunscreen regularly in the population are likely to result in sizeable reductions in melanoma incidence (as well as other skin tumours) into the future.

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*Study concept and design*: Whiteman, Olsen.

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*Statistical analysis*: Wilson.

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*Administrative, technical, or material support*: Loyalka, Biswas.

*Study supervision*: Whiteman.

**REFERENCES**

1 IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Solar and Ultraviolet Radiation. *IARC Monographs on the evaluation of carcinogenic risks to humans.* Vol 100D. Lyon (FRC): World Health Organisation; 2012.

2. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Solar and Ultraviolet Radiation. *IARC monographs on the evaluation of carcinogenic risks to humans.* Vol 55. Lyon (FRC): World Health Organisation; 1992.

3 Armstrong BK, Kricker A. How much melanoma is caused by sun exposure? *Melanoma Res* 1993; **3**: 395-401.

4 Olsen CM, Wilson LF, Green AC *et al.* Cancers in Australia attributable to exposure to solar ultraviolet radiation and prevented by regular sunscreen use. *Aust N Z J Public Health* 2015; **39**: 471-6.

5 Erdmann F, Lortet-Tieulent J, Schuz J *et al.* International trends in the incidence of malignant melanoma 1953-2008--are recent generations at higher or lower risk? *Int J Cancer* 2013; **132**: 385-400.

6 Whiteman DC, Green AC, Olsen CM. The Growing Burden of Invasive Melanoma: Projections of Incidence Rates and Numbers of New Cases in Six Susceptible Populations through 2031. *J Invest Dermatol* 2016; **136**: 1161-71.

7 Brash DE. UV signature mutations. *Photochem Photobiol* 2015; **91**: 15-26.

8 Premi S, Wallisch S, Mano CM *et al.* Photochemistry. Chemiexcitation of melanin derivatives induces DNA photoproducts long after UV exposure. *Science* 2015; **347**: 842-7.

9 Mancebo SE, Hu JY, Wang SQ. Sunscreens: A Review of Health Benefits, Regulations, and Controversies. *Dermatol Clin* 2014; **32**: 427-38.

10 Hill VK, Gartner JJ, Samuels Y *et al.* The genetics of melanoma: recent advances. *Annual review of genomics and human genetics* 2013; **14**: 257-79.

11 Hodis E, Watson IR, Kryukov GV *et al.* A landscape of driver mutations in melanoma. *Cell* 2012; **150**: 251-63.

12 Lawrence MS, Stojanov P, Polak P *et al.* Mutational heterogeneity in cancer and the search for new cancer-associated genes. *Nature* 2013; **499**: 214-8.

13 Shain AH, Bastian BC. The Genetic Evolution of Melanoma. *N Engl J Med* 2016; **374**: 995-6.

14 Olsen CM, Wilson LF, Green AC *et al.* Prevention of DNA damage in human skin by topical sunscreens. *Photodermatology, Photoimmunology & Photomedicine* 2017; **(in press)**.

15 Viros A, Sanchez-Laorden B, Pedersen M *et al.* Ultraviolet radiation accelerates BRAF-driven melanomagenesis by targeting TP53. *Nature* 2014.

16 Green AC, Williams GM, Logan V *et al.* Reduced melanoma after regular sunscreen use: randomized trial follow-up. *J Clin Oncol* 2011; **29**: 257-63.

17 IARC Working Group on the Evaluation of Cancer-preventive Agents. *Sunscreens.* Lyon, France2001.

18 Dennis LK, Beane Freeman LE, VanBeek MJ. Sunscreen use and the risk for melanoma: a quantitative review. *Ann Intern Med* 2003; **139**: 966-78.

19 Huncharek M, Kupelnick B. Use of topical sunscreens and the risk of malignant melanoma: a meta-analysis of 9067 patients from 11 case-control studies. *Am J Public Health* 2002; **92**: 1173-7.

20 Green AC, Williams GM. Point: sunscreen use is a safe and effective approach to skin cancer prevention. *Cancer Epidemiol Biomarkers Prev* 2007; **16**: 1921-2.

21 Cho E, Rosner BA, Feskanich D *et al.* Risk factors and individual probabilities of melanoma for whites. *J Clin Oncol* 2005; **23**: 2669-75.

22 Ghiasvand R, Weiderpass E, Green AC *et al.* Sunscreen Use and Subsequent Melanoma Risk: A Population-Based Cohort Study. *J Clin Oncol* 2016.

23 Nijsten T. Sunscreen Use in the Prevention of Melanoma: Common Sense Rules. *J Clin Oncol* 2016; **34**: 3956-8.

24 American Academy of Dermatology. What sunscreen should I use? <https://www.aad.org/media/stats/prevention-and-care/sunscreen-faqs>. Accessed 18 November, 2016.

25 US Department of Health and Human Services. *The Surgeon General’s Call to Action to Prevent Skin Cancer.* In: U.S. Dept of Health and Human Services Office of the Surgeon General, ed. Washington, DC., 2014.

26 Centers for Disease Control and Prevention (CDC). Sun Safety. *Skin Cancer* 2016; <http://www.cdc.gov/cancer/skin/basic_info/sun-safety.htm>. Accessed 18 November 2016, 2016.

27 U.S. Food and Drug Administration (FDA). Sunscreens and Sun Protection. <http://www.fda.gov/drugs/resourcesforyou/consumers/buyingusingmedicinesafely/understandingover-the-countermedicines/ucm239463.htm>. Accessed 18 February, 2016.

28 American Cancer Society (ACS). Skin Cancer Prevention and Early Detection. 2016. https://www.cancer.org/cancer/skin-cancer/prevention-and-early-detection/uv-protection.html. Accessed 18 November 2016, 2016.

29 Cancer Council Australia. Preventing Skin Cancer. <http://www.cancer.org.au/preventing-cancer/sun-protection/preventing-skin-cancer/>. Accessed 18 November, 2016.

30 Cancer Research UK. Cancer Research UK. Ways to enjoy the sun safely. http://www.cancerresearchuk.org/about-cancer/causes-of-cancer/sun-uv-and-cancer/ways-to-enjoy-the-sun-safely. Accessed 20 January, 2017.

31 British Association of Dermatologists. Sun Safety Tips. http://www.bad.org.uk/for-the-public/skin-cancer/sunscreen-fact-sheet#sun-safety-tips. Accessed 20 January, 2017.

32 Barendregt JJ, Veerman JL. Categorical versus continuous risk factors and the calculation of potential impact fractions. *J Epidemiol Community Health* 2010; **64**: 209-12.

33 Soerjomataram I, de Vries E, Engholm G *et al.* Impact of a smoking and alcohol intervention programme on lung and breast cancer incidence in Denmark: An example of dynamic modelling with Prevent. *Eur J Cancer* 2010; **46**: 2617-24.

34 Zamoiski RD, Cahoon EK, Michal Freedman D *et al.* Self-reported sunscreen use and urinary benzophenone-3 concentrations in the United States: NHANES 2003-2006 and 2009-2012. *Environ Res* 2015; **142**: 563-7.

35 Cokkinides V, Weinstock M, Glanz K *et al.* Trends in sunburns, sun protection practices, and attitudes toward sun exposure protection and tanning among US adolescents, 1998-2004. *Pediatrics* 2006; **118**: 853-64.

36 Centre for Epidemiology and Evidence. *2010 Report on Adult Health from the New South Wales Population Health Survey.* Sydney (AUST), 2011.

37 Centre for Epidemiology and Evidence. *New South Wales School Students' Health Behaviours Survey: 2011 Report.* Sydney (AUST), 2013.

38 Moller B, Fekjaer H, Hakulinen T *et al.* Prediction of cancer incidence in the Nordic countries: empirical comparison of different approaches. *Stat Med* 2003; **22**: 2751-66.

39 Whiteman DC, Whiteman CA, Green AC. Childhood sun exposure as a risk factor for melanoma: a systematic review of epidemiologic studies. *Cancer, Causes and Control* 2001; **12**: 69-82.

40 de Vries E, Arnold M, Altsitsiadis E *et al.* Potential impact of interventions resulting in reduced exposure to ultraviolet (UV) radiation (UVA and UVB) on skin cancer incidence in four European countries, 2010-2050. *Br J Dermatol* 2012; **167 Suppl 2**: 53-62.

41 Autier P, Dore JF, Negrier S *et al.* Sunscreen use and duration of sun exposure: a double-blind, randomized trial. *J Natl Cancer Inst* 1999; **91**: 1304-9.

42 Autier P, Boniol M, Dore JF. Sunscreen use and increased duration of intentional sun exposure: still a burning issue. *Int J Cancer* 2007; **121**: 1-5.

**SUPPORTING INFORMATION**

**Table S1.** Number of cases of melanoma by country and sex in base year (2011), total estimated expected cases 2012-2031 with and without interventions, using the effect estimate for a protective effect of sunscreen from the Norwegian Women and Cancer Study.

**Figure S1.** Number of cases of melanoma in base year (2011) and average annual cases for four 5-year time periods (2012-2016, 2017-2021, 2022-2026, 2027-2031) under sunscreen intervention scenarios implemented at different ages, using Relative Risks from the Nambour Trial.

**Figure S2:** Number of cases of melanoma in base year (2011) and average annual cases for four 5-year time periods (2012-2016, 2017-2021, 2022-2026, 2027-2031) under different sunscreen intervention scenarios using alternative Relative Risks from Ghiasvand (2016).

**Figure S3:** Number of cases melanoma in base year (2011) and average annual cases for four 5-year time periods (2012-2016, 2017-2021, 2022-2026, 2027-2031) under sunscreen intervention scenarios implemented at different ages, using alternative Relative Risks from Ghiasvand (2016).

**Figure 1.** Cumulative melanoma incidence curves for a) United States and b) Australia.

This figure shows the magnitude of the protective effects of the various sunscreen intervention scenarios (see text and Table 1), represented as the absolute difference in cumulative melanoma incidence between baseline (‘no change’) and each intervention in the two populations from 2011 to 2031.

**Figure 2.** Theoretical cumulative melanoma incidence curves for Australia to the year 2081.

This figure shows the potential magnitude of the protective effects of a sunscreen intervention in school-aged children (Model 5, see Table 1) with 70 years of follow-up, represented as the absolute difference in cumulative melanoma incidence between baseline (‘no change’) and the intervention in the Australian population from 2011 to 2081.

**Table 1.** Summary of intervention scenarios.

|  |  |
| --- | --- |
| **Scenario Name** | **Description** |
|  |  |
| Model 1:Partial Uptake - 10 year implementation | Sunscreen use increases by 5% each year over a 10 year period – 2012-2022 (for both men and women and all ages) |
|  |  |
| Model 2: *Theoretical maximum intervention*Full Uptake - immediate implementation | Sunscreen use becomes mandatory and increases to 100% use by males and females (across all age groups) in year 1 (2012). |
|  |  |
| Model 3: *Delayed maximum intervention*Full Uptake - 10 year implementation | Sunscreen use becomes mandatory, increasing to 100% use by males and females (across all age groups) over a 10 year period (2012-2022). |
|  |  |
| Model 4: Partial Uptake < 75 years - 10 year implementation | Sunscreen use increases by 5% each year over a 10 year period – 2012-2022 (for both men and women) but only in people aged less than 75 years. |
|  |  |
| Model 5:School-based intervention | Sunscreen use becomes mandatory for school-aged children (0-17 years) from year 1 (2012) and this 100% usage continues as this cohort ages (i.e. by 2031, 100% of people aged 0 to 37 years are all using sunscreen daily)  |
|  |  |
| Model 6:Working-age intervention | Sunscreen use becomes mandatory for people of “prime” working-age (20-45 years) from year 1 (2012) and this 100% usage continues as this cohort ages (i.e. by 2031, 100% of people aged 20 to 65 years are all using sunscreen daily) |
|  |  |
| Model 7:Pre-retirement age intervention | Sunscreen use becomes mandatory for people of pre-retirement age (45-65 years) from year 1 (2012) and this 100% usage continues as this cohort ages (i.e. by 2031, 100% of people aged 45 to 85 years are all using sunscreen daily) |
|  |  |

**Table 2.** Number of cases of melanoma by country and sex in base year (2011), total estimated expected cases 2012-2031 with and without interventions.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Intervention** |  | **United States (white population)** |  | **Australia** |
|  |  | **Men** | **Women** | **Persons** |  | **Men** | **Women** | **Persons** |
|  |  |  |  |  |  |  |  |  |
|  | Base year - 2011 (cases) | 41,766 | 30,000 | 71,766 |  | 6,734 | 4,835 | 11,570 |
|  | Trend only 2012-2031 (cases) | 1,237,298 | 845,745 | 2,083,053 |  | 171,855 | 112,365 | 284,220 |
|  |  |  |  |  |  |  |  |  |
| Model 1: | Intervention 2012-2031 (cases) | 1,097,713 | 754,287 | 1,852,000 |  | 154,055 | 102,095 | 256,149 |
| Partial Uptake - 10 year implementation | Preventable cases (%) | 11.3% | 10.8% | 11.1% |  | 10.4% | 9.1% | 9.9% |
|  |  |  |  |  |  |  |  |  |
| Model 2:*Theoretical maximum intervention* | Intervention 2012-2031 (cases) | 756,149 | 530,053 | 1,286,181 |  | 110,882 | 76,921 | 187,803 |
| Full Uptake - immediate implementation | Preventable cases (%) | 38.9% | 37.3% | 38.3% |  | 35.5% | 31.5% | 33.9% |
|  |  |  |  |  |  |  |  |  |
| Model 3: *Delayed maximum intervention* | Intervention 2012-2031 (cases) | 881,574 | 612,883 | 1,494,447 |  | 126,496 | 86,251 | 212,746 |
| Full Uptake - 10 year implementation | Preventable cases (%) | 28.8% | 27.5% | 28.3% |  | 26.4% | 23.2% | 25.1% |
|  |  |  |  |  |  |  |  |  |
| Model 4: Partial Uptake - 10 year implementation | Intervention 2012-2031 (cases) | 1,136,809 | 770,872 | 1,907,713 |  | 158,993 | 104,474 | 263,463 |
| (< 75 years only) | Preventable cases (%) | 8.1% | 8.9% | 8.4% |  | 7.5% | 7.0% | 7.3% |
|  |  |  |  |  |  |  |  |  |
| Model 5: School age intervention | Intervention 2012-2031 (cases) | 1,229,117 | 831,426 | 2,060,500 |  | 170,967 | 111,611 | 282,579 |
|  | Preventable cases (%) | 0.7% | 1.7% | 1.1% |  | 0.5% | 0.7% | 0.6% |
|  |  |  |  |  |  |  |  |  |
| Model 6: Working age intervention | Intervention 2012-2031 (cases) | 1,147,489 | 737,287 | 1,884,787 |  | 160,021 | 102,092 | 262,116 |
|  | Preventable cases (%) | 7.3% | 12.8% | 9.5% |  | 6.9% | 9.1% | 7.8% |
|  |  |  |  |  |  |  |  |  |
| Model 7: Pre-retirement age intervention | Intervention 2012-2031 (cases) | 959,500 | 670,915 | 1,630,436 |  | 135,878 | 92,254 | 228,134 |
|  | Preventable cases (%) | 22.5% | 20.7% | 21.7% |  | 20.9% | 17.9% | 19.7% |
|  |  |  |  |  |  |  |  |  |

Numbers (except for base year 2011) represent the cumulative total number of cases projected over the 20 year interval 2011-2031 based on prior published evidence.[6](#_ENREF_6)