Narrative Review Article

The Effectiveness of Sunscreen Against Ultraviolet Radiation: A Narrative Review with Implications for Adolescents

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ABSTRACT

Ultraviolet (UV) radiation remains a major public health concern because of its association with skin damage and an increased risk of skin cancer. Melanoma incidence has increased in recent years due to contributing factors such as tanning behaviors, social influences, and limited awareness of UV radiation risks. Inconsistent sunscreen use and inadequate sun-protective behaviors may increase cumulative UV radiation exposure during adolescence. This narrative review synthesizes evidence from dermatological, clinical, behavioral, and laboratory studies examining the effects of UV radiation on the skin, the effectiveness of sunscreen in reducing UV-induced skin damage, and factors influencing sun-protective behaviors, with an emphasis on implications for adolescents. Overall, the reviewed literature suggests that education about UV radiation risks, together with consistent photoprotective measures, may reduce cumulative UV radiation exposure and contribute to lowering melanoma risk over time. Although adolescent-specific evidence remains limited, adolescence represents a crucial period for establishing lifelong sun-protective behaviors that may reduce future skin cancer risk.

Keywords: Ultraviolet radiation; sunscreen; adolescents; skin cancer; melanoma; photoprotection

INTRODUCTION

Ultraviolet (UV) radiation represents a significant public health concern because of its associations with cellular damage and skin cancer (1). Melanoma, the most dangerous form of skin cancer, has shown increasing incidence rates among adolescents and young adults, although incidence trends vary across populations. Increased melanoma incidence in adolescents has been linked to factors such as the prevalence of tanning culture, media influence, and a lack of education about the risks posed by excessive UV radiation (2). UV radiation penetrates the various layers of the skin (epidermis and dermis), allowing it to damage intracellular components. Despite the availability of sunscreen products, many adolescents fail to incorporate sunscreen into their daily routines. Furthermore, many adolescents remain uninformed about the risks of melanoma associated with excessive UV radiation exposure and inconsistent sunscreen use. Irregular sunscreen use and limited awareness may increase cumulative UV exposure during adolescence and could contribute to melanoma risk later in adulthood.

Adolescence represents a crucial period in establishing sun-protective behaviors because behaviors developed during these years often persist later into adulthood. Education about skin cancer and UV radiation is essential because it helps establish lifelong sunscreen

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habits. Increasing awareness through pediatricians and community education may encourage sun-protective behaviors and contribute to reducing melanoma risk over time. This narrative review examines the current evidence regarding UV radiation, sunscreen use, and melanoma prevention, with particular emphasis on the implications of these findings for adolescents, including sunscreen application practices, sun-protective behaviors, melanoma education, and parental involvement. Because relatively few studies focus exclusively on adolescent populations, this review also discusses evidence from adult and general populations where appropriate while distinguishing direct evidence from implications for adolescents.

ULTRAVIOLET RADIATION AND MELANOMA DEVELOPMENT

UV radiation is one of the primary environmental factors contributing to elevated melanoma incidence. UV radiation consists of electromagnetic waves emitted by the sun at wavelengths ranging from approximately 100 to 400 nanometers (nm). UV radiation intensity is influenced by several factors: altitude, height of the sun, cloud cover, and the ozone layer. UV radiation can also originate from other sources, notably tanning beds. According to the World Health Organization (3), UV radiation consists of three types: UVA, UVB, and UVC. UVA rays have the longest wavelength, allowing them to reach deeper structures of the skin; UVB rays have intermediate wavelengths, and are primarily absorbed by the epidermis. Nearly all UVC radiation is absorbed by atmospheric filtering: water vapor, the ozone layer, oxygen, and carbon dioxide. In contrast, UVA and UVB rays are less affected by atmospheric filtering. UVA and UVB rays account for most of the radiation reaching earth's surface. D'Orazio *et al*. (4) explain that UVA and UVB rays pose the greatest threat to the skin and distinguish between their biological effects. D'Orazio *et al*. (4) reported that UVA rays penetrate the dermis, where they cause indirect DNA damage through oxidative injury. This damage creates mutations, promotes nucleotide mispairing, and contributes to tumor formation. UVB rays cause more surface-level damage within the epidermis (3), primarily causing inflammation and sunburn. D'Orazio *et al*. (4) describe this process as direct DNA absorption. During this process, nucleotide bases can fuse together and produce free radicals, often contributing to skin inflammation following UV radiation exposure (5).

Both oxidative injury caused by UVA radiation and direct absorption caused by UVB radiation place substantial stress on the skin's repair mechanisms. D'Orazio *et al*. (4) also found that UV radiation poses a significant risk to the nucleotide excision repair mechanism. Damage to this repair mechanism reduces the cell's ability to repair photoproducts, structural mutations, and other UV-induced DNA lesions. As a consequence of this accumulated cellular and DNA damage, UV radiation has been identified as a major initiator and promoter of several forms of skin cancer, namely basal cell carcinoma, squamous cell carcinoma, and malignant melanoma. These findings suggest that UV radiation contributes to both the initiation and progression of skin cancers. Because D'Orazio *et al*. (4) synthesized molecular and cellular evidence rather than relying on a single experimental model, their findings provide a comprehensive explanation for the biological mechanisms linking UV radiation to melanoma development. Notably, D'Orazio *et al*. (4) focused on the molecular mechanisms of UV-induced DNA damage and carcinogenesis rather than evaluating sunscreen use, sunscreen adherence, or melanoma incidence in human populations. Although environmental UV exposure plays a major role in melanoma development, researchers have also identified genetic factors that influence an individual's susceptibility to melanoma. For example, variations in the melanocortin 1 receptor (MC1R) are associated with sensitivity to UV radiation and elevated melanoma risk. Collectively, these results emphasize that melanoma risk is influenced by both environmental conditions and genetic susceptibility. These factors are particularly relevant when considering melanoma among adolescents, a population that is often overlooked despite sharing many of the same risk factors observed in adults. Melanoma is relatively rare in adolescents aged 15–19. As a result, adolescent melanoma often goes undetected because both patients and clinicians are less likely to suspect it. In their review of pediatric melanoma, McMullan and Grant-Kels (6) reported that adolescents accounted for approximately 79% of pediatric melanoma cases, reflecting the age distribution within pediatric melanoma. Adolescent melanoma presents unique diagnostic challenges, as the appearance of adolescent melanoma is very similar to that of benign nevi (non-cancerous moles). However, because adolescent melanoma remains relatively rare, further large-scale studies are needed to better characterize its clinical presentation and long-term outcomes. Ultimately, the literature emphasizes an important role of UV

radiation in melanoma development and the importance of reducing UV exposure during adolescence. Consequently, sunscreen use has emerged as one of the most widely recommended preventive measures against UV radiation exposure and melanoma.

SUNSCREEN MECHANISMS AND EVIDENCE FOR EFFECTIVENESS

Sunscreens reduce the amount of UV radiation that reaches the skin. Sunscreen components generally fall into two categories: mineral (inorganic) UV filters and organic (chemical) UV filters. Mineral filters such as zinc oxide and titanium dioxide protect the skin by absorbing, scattering, and reflecting a small portion of UV radiation, thereby reducing the amount of UV energy that penetrates the skin and its structures. Likewise, organic UV filters absorb specific wavelengths of UV radiation and convert the absorbed energy into heat before it can cause significant damage within the skin (7). Many sunscreens combine mineral and organic filters to maximize UV protection. Sunscreens are evaluated using the Sun Protection Factor (SPF), which measures protection against UVB-induced erythema (sunburn). Broad-spectrum labeling indicates that a sunscreen provides protection against both UVA and UVB radiation, whereas SPF specifically reflects protection against UVB-induced erythema (8). According to the American Academy of Dermatology (9), individuals should use a broad-spectrum sunscreen with an SPF of 30 or higher; the broad-spectrum designation indicates protection against both UVA and UVB radiation, while the SPF value primarily reflects protection against UVB-induced erythema. He *et al*. (10) reported that naturally derived ingredients such as lignin may improve the laboratory SPF performance of sunscreen formulations. However, these findings reflect laboratory formulation testing rather than clinical effectiveness, sunscreen adherence, or melanoma prevention in real-world populations. In addition to lignin, He *et al*. (10) investigated other naturally derived compounds that may enhance sunscreen performance, including silymarin. Similarly, silymarin demonstrated improved laboratory SPF performance when combined with mineral UV filters. These findings suggest potential formulation benefits but do not demonstrate improved sunscreen use or melanoma prevention in real-world populations.

Beyond laboratory formulation studies, clinical research has evaluated whether sunscreen effectively reduces melanoma risk. Green *et al*. (11) evaluated melanoma incidence as the primary clinical outcome of long-term daily sunscreen use. In this study, they conducted a randomized controlled trial involving 1,621 adults in Queensland, Australia, in which researchers randomly assigned participants to either a daily sunscreen group or a discretionary-use group. Green *et al*. (11) used questionnaires, pathology reports, and cancer registries throughout the study. They found that the participants applying sunscreen every day had 11 reported cases of melanoma by the end of the study. Conversely, participants in the discretionary-use group reported 22 cases of melanoma by the end of the study. The randomized controlled design strengthened the evidence that consistent sunscreen use reduces melanoma incidence in the adult population studied. Because the study did not specifically evaluate adolescents, its implications for adolescent melanoma prevention should be interpreted cautiously.

Although Green *et al*. (11) demonstrated sunscreen effectiveness among the adult participants in a randomized controlled trial, researchers have also examined the potential impact of sunscreen use for the modeled populations. Olsen *et al*. (12) developed predictive population models using data from the U.S. white and the Australian general populations to estimate future melanoma incidence from 2012 through 2031. Additionally, they calculated a Potential Impact Factor (PIF), estimating the number of melanoma cases that would be prevented under various sunscreen use scenarios. Combining projections through 2031, the PIF, and prevalence surveys indicating proportions of the populations with melanoma at specific points in time, they identified a hypothetical situation with a maximum and medium sunscreen use scenario. Using these predictive models, the researchers estimated that between 231,053 and 797,000 melanoma cases would be prevented in the U.S. white population and between 28,071 and 96,000 cases of melanoma would be prevented in the Australian general population. These estimates were generated using predictive population models based on assumptions regarding future sunscreen use among U.S. white and Australian general populations and therefore represent projected rather than observed reductions in melanoma incidence. The predictive models suggest that increased sunscreen use could prevent substantial numbers of melanoma cases for the modeled populations.

While Green *et al*. (11) focused on observations from a randomized controlled study, Olsen *et al*. (12) measured theoretical outcomes of populations using a hypothetical model. Together, these studies suggest that

improving knowledge of melanoma risk and encouraging sun-protective behaviors requires both individual-level education and population-level public health interventions. However, because Olsen *et al*. (12) relied on predictive population models rather than observed outcomes, their projections depend on assumptions about future sunscreen use and melanoma incidence. Although these findings were not obtained from adolescent populations, the results suggest that regular sunscreen habits established during adolescence may contribute to reduced melanoma risk later in adulthood because UV radiation damage accumulates over time, and adolescence represents a critical period for reducing lifetime UV exposure.

BEHAVIORAL AND EDUCATIONAL FACTORS INFLUENCING SUNSCREEN USE

Although there have been numerous studies on melanoma and UV radiation risks as well as the effectiveness of consistent sunscreen application, studies consistently suggest that adolescents fail to use sunscreen consistently. In addition, research suggests that this may be due to factors such as the prevalence of tanning culture, media influence, and insufficient education regarding melanoma risks in adolescents. Research suggests that parental modeling and clinician counseling can help address gaps in adolescent knowledge. In a recent study, Hang *et al*. (13) conducted a cross-sectional survey of 51 patients with skin of color (Fitzpatrick skin types III–VI) attending a dermatology clinic in Australia. Participants completed questionnaires assessing sunscreen-use frequency, application amount, reapplication practices, and misconceptions about sunscreen. In analyzing the recorded data, researchers applied chi-square tests as well as logistic regressions in order to evaluate expected versus observed frequencies and develop predictive models. Hang *et al*. (13) reported that only 33.3% of participants used sunscreen regularly, while 32.9% reported occasional sunscreen use. These findings indicate that 33.8% of participants did not use sunscreen at all. Furthermore, only 57.5% of participants reported reapplying sunscreen after prolonged periods of exposure and 79.5% reported applying less than the recommended one ounce.

According to the American Academy of Dermatology (9), most adults require approximately one ounce of sunscreen to cover skin not protected by clothing, although the amount needed may vary depending on body size. Clinical guidelines recommend using a broad-spectrum sunscreen with an SPF of 30 or higher, applying an adequate amount to cover exposed skin, reapplying every two hours and after swimming or excessive sweating, choosing a water-resistant sunscreen during water activities, and avoiding intentional tanning. Additional sun-protective measures, including wearing protective clothing, wide-brimmed hats, UV-blocking sunglasses, seeking shade, and avoiding sun exposure during peak UV radiation hours, further reduce UV radiation exposure and should be used in addition to sunscreen rather than as substitutes for it. Sunscreen should not be used to justify prolonged or intentional sun exposure but rather as one component of a comprehensive sun-protection strategy. These clinically recommended practices have greater relevance to adolescent sun protection than formulation-level differences in individual sunscreen ingredients. According to Hang *et al*. (13), only 19.6% of participants recognized the risks associated with not using sunscreen. This finding emphasizes that many individuals fail to apply the recommended amount of sunscreen, do not reapply sunscreen after prolonged sun exposure, and/or use sunscreen inconsistently. These behaviors substantially reduce the protection provided by broad-spectrum sunscreen, regardless of the formulation used. Collectively, these findings suggest that sunscreen use is influenced by multiple interacting factors. Limited knowledge of melanoma risk may reduce adolescents' perceived susceptibility to UV damage, while parental modeling, peer norms, and tanning culture may reinforce behaviors that increase UV exposure. Because this study measured sunscreen behaviors and knowledge rather than melanoma incidence or sunscreen effectiveness, its findings should not be interpreted as evidence that sunscreen reduces melanoma risk among adolescents, but rather as evidence that improving sunscreen use requires better education interventions that encourage photoprotective behaviors.

Researchers have also investigated behavioral and social influences that encourage adolescents to seek additional UV exposure through intentional tanning. Whereas Hang *et al*. (13) conducted a cross-sectional survey examining sunscreen knowledge and behaviors, Holman *et al*. (14) used an observational study to investigate the social and environmental factors influencing intentional tanning among adolescents. The study examined the factors influencing the prevalence of intentional tanning in adolescents. For example, on an individual level, factors encouraging tanning included being female, preferring tanner skin, and engaging in appearance-based activities such as tanning. The

researchers also found that on a social level, parental modeling and peer norms influenced adolescents to participate in intentional tanning. The researchers also found that an important environmental factor was proximity to tanning salons offering services for tanning: spray tans, airbrush tans, and tanning beds. The study by Holman *et al*. (14) suggested that multiple influences from an adolescent's life may encourage intentional tanning. Together, these studies suggest that inadequate sunscreen use results not only from limited knowledge but also from social and environmental influences that encourage UV exposure. These findings reinforce current clinical recommendations that adolescents avoid intentional tanning, as it unnecessarily increases cumulative UV radiation exposure and melanoma risk. However, because Holman *et al*. (14) examined behavioral associations, additional longitudinal research is needed to determine how these social influences shape sunscreen habits over time.

Because parents and peers strongly influence adolescent behavior, they may also play an important role in promoting sunscreen use and melanoma awareness. To address gaps in sunscreen use and melanoma awareness, researchers have explored methods of improving skin cancer education among adolescents. Gordon *et al*. (15) conducted qualitative interviews with primary care providers caring for adolescents (ages 13–15) to examine clinician counseling regarding melanoma prevention. Gordon *et al*. (15) found that pediatricians generally supported skin cancer risk-reduction counseling for adolescents but reported multiple barriers affecting the consistent delivery of this counseling. These findings highlight challenges in routinely incorporating skin cancer prevention counseling into adolescent primary care. In fact, researchers identified that nationally, among approximately 500 pediatricians, only about 45% of pediatricians consistently addressed skin cancer prevention with adolescent patients. These findings suggest that inconsistent clinician counseling may contribute to gaps in adolescents' knowledge of skin cancer prevention. Although clinician counseling may improve awareness and perceived risk of UV exposure, the study did not evaluate whether increased knowledge translated into sustained sunscreen use, reduced UV exposure, or lower melanoma incidence. Increasing adolescents' perceived risk of UV exposure may encourage greater adoption of sunscreen and other sun-protective behaviors, although knowledge alone does not necessarily translate into behavior change.

Unlike Gordon *et al*.'s (15) qualitative interview study, Tripp *et al*. (16) conducted a review of melanoma prevention strategies in general populations. Through their research, they analyzed melanoma incidence, risk factors, and prevention strategies. Specifically, Tripp *et al*. (16) evaluated scientific evidence regarding increasing melanoma incidence and public health initiatives to prevent further exponential increases in melanoma rates. The study found that skin cancer incidence increased by approximately 3% yearly despite a decrease in cancer rates generally, emphasizing the association between excessive UV radiation exposure and elevated melanoma rates. The researchers also suggested reducing melanoma incidence by reducing sun exposure, indoor tanning, and promoting education. Taken together, these findings suggest that educational interventions primarily improve knowledge and awareness of melanoma risk, whereas additional behavioral and environmental interventions are needed to increase consistent sunscreen use and reduce UV exposure.

However, education alone may not be sufficient to improve outcomes. Unlike the educational interventions described above, Mayer *et al*. (17) focused on secondary prevention through melanoma screening rather than changing sunscreen behaviors or reducing UV exposure. Through the examination of melanoma screening programs and physician-performed skin examinations, Mayer *et al*. (17) evaluated the role of screening in the earlier detection of melanoma and related clinical outcomes rather than the primary prevention of melanoma. They reviewed evidence regarding melanoma screening and its potential role in reducing melanoma-related outcomes. The studies conducted in the U.S. and Australian general populations suggested that screening programs were associated with earlier detection of melanoma and improved clinical outcomes. These findings suggest that education, community-based interventions, and parental involvement encourage sun-protective behaviors and help reduce UV exposure. In contrast, melanoma screening does not prevent melanoma from developing but instead supports earlier detection, which may improve clinical outcomes.

Collectively, the reviewed studies demonstrate that successful melanoma prevention requires multiple complementary approaches. Educational interventions increase awareness of melanoma risk, clinician counseling reinforces preventive recommendations, parental modeling and peer norms influence adolescents' daily sun-protective behaviors, and public health initiatives discourage intentional tanning and excessive UV exposure. Screening complements these strategies

by promoting earlier detection as opposed to reducing melanoma incidence. Together, these approaches support a more comprehensive photoprotection strategy throughout adolescence. The principal studies discussed in this review are summarized in Table 1.

Table 1. *Summary of the key studies included in this narrative review.*

Study	Population	Design	Exposure/ Intervention	Main Outcome	Key Finding	Relevance to Adolescents	Limitations
Green *et al*. (11)	1,621 Australian adults (25–75 years)	Randomized controlled trial	Daily sunscreen use	Melanoma incidence	Daily sunscreen reduced invasive melanoma	Suggests benefits of lifelong sunscreen use	Adults only
Olsen *et al*. (12)	General Australian and U.S. white population	Modeling study	Increased sunscreen use	Melanoma prevention	Predicted fewer melanoma cases with greater sunscreen use	Supports prevention efforts	Based on projections
Hang *et al*. (13)	51 Australian dermatology patients with skin of color (Fitzpatrick III–VI)	Cross-sectional study	Sunscreen use	Sun-protective behaviors	Daily sunscreen use was low, with poor reapplication and misconceptions about sunscreen	Highlights sunscreen knowledge gaps that may inform adolescent education	Cannot establish causation; not adolescent-specific
Holman *et al*. (14)	U.S. adolescents	Systematic review	Intentional tanning	Intentional tanning behavior	Parental, peer, and environmental influences contributed to intentional tanning	Identifies factors influencing adolescent tanning behaviors	Observational evidence; cannot establish causation
Gordon *et al*. (15)	Primary care providers caring for adolescents (13–15)	Qualitative interviews	Clinician counseling	Melanoma prevention counseling	Many providers supported melanoma prevention counseling but reported barriers to providing skin cancer education	Highlights the importance of clinician counseling for adolescents	Did not assess behavioral or clinical outcomes
Mayer *et al*. (17)	General populations (screening studies)	Review	Skin cancer screening	Early melanoma detection	Screening was associated with earlier melanoma detection but not melanoma prevention	Relevant to high risk adolescents	Limited adolescent-specific evidence
Tripp *et al*. (16)	General populations	Review	Melanoma prevention strategies	Protective behaviors	Reducing UV exposure, indoor tanning, and improving education may reduce melanoma incidence	Supports population-level prevention strategies applicable to adolescents	Limited long-term outcome data

LIMITATIONS

A major limitation of the current evidence is the scarcity of longitudinal studies conducted specifically in adolescent populations. Although current literature consistently highlights the importance of sunscreen use and education in reducing UV exposure and melanoma risk, several limitations remain among the existing body of research. Many of the studies included in this review were conducted in adult or general-population cohorts, requiring cautious interpretation when applying the findings to adolescents. Regarding melanoma specifically, many of the studies within this review focus on reducing melanoma incidence and UV radiation exposure for the general population, rather than adolescents specifically, partly because adolescent melanoma is relatively rare and because conducting long-term research involving minors presents additional ethical and practical challenges. Several findings were derived from cross-sectional surveys, which can identify associations but cannot establish causality. In addition, modeled projections estimating melanoma prevention rely on assumptions and therefore should not be interpreted as direct clinical evidence. This limitation applies to several studies included in this review, including those by Olsen *et al*. (12), Green *et al*. (11), Hang *et al*. (13), and Mayer *et al*. (17). Future studies should focus specifically on adolescents to better understand melanoma prevention and improve targeted educational interventions. Future research should prioritize longitudinal studies following adolescents into adulthood to evaluate sunscreen use, educational interventions, parental involvement, and melanoma incidence. Although educational interventions often improve sunscreen knowledge and short-term protective behaviors, there is limited evidence demonstrating that these behavioral changes are maintained over the long term.

CONCLUSION

Ultraviolet radiation exposure remains an important public health concern, making effective photoprotection a priority throughout adolescence and adulthood. The literature reviewed demonstrates that daily application of broad-spectrum sunscreen reduces UV radiation exposure and UV-induced skin damage when used correctly. Evidence from randomized controlled trials conducted primarily in adults, together with predictive population models, suggests that long-term consistent sunscreen use may contribute to lowering melanoma risk, though direct evidence demonstrating this effect specifically in adolescents remains limited. However, sunscreen alone is insufficient without education about UV radiation and sun-protective behaviors. Effective photoprotection requires selecting a broad-spectrum sunscreen with SPF 30 or higher, applying an adequate amount, reapplying regularly, using water-resistant sunscreen during swimming or activities that cause excessive sweating, wearing protective clothing during prolonged sun exposure, and avoiding intentional tanning. These interventions may help adolescents establish lifelong sun-protective habits. Future research focusing specifically on adolescent populations will further strengthen prevention strategies and improve long-term skin health outcomes. Overall, sunscreen should be considered one component of a comprehensive ultraviolet protection strategy, and adolescence represents a valuable period for establishing lifelong sun-protective behaviors.

CONFLICT OF INTEREST

The author declares no conflicts of interest related to this work.

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