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Review Article

The Science of Shielding: Evaluating Sunscreen Safety and Efficacy

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ABSTRACT

Health experts recommend using sunscreen to reduce skin damage from UV rays. While SPF measures protection against UVB rays, it doesn't fully assess protection against UVA rays. There's no agreed method to test UVA protection, though consumers want sunscreens that protect against both UVB and UVA. Most sunscreen ingredients are safe based on studies, and sunscreens effectively prevent UV damage. Using broad-spectrum sunscreen regularly can help improve public health by reducing UV exposure.

INTRODUCTION

The sun emits different types of radiation: infrared (IR), visible light, and ultraviolet (UV). UV radiation, with the shortest wavelength and highest energy, is the most harmful. It's divided into three types: UVA (320-400 nm), UVB (290-320 nm), and UVC (100-280 nm). UVA has the least energy and causes tanning and aging, while UVB causes sunburn and deeper skin damage. UVC is the most harmful but is absorbed by the ozone layer. About 95% of UV radiation reaching Earth is UVA, and around 5% is UVB. Both can damage DNA and cause skin issues like aging, sunburn, and cancer. UVA and UVB also produce reactive oxygen species (ROS) that harm the skin. Melanin in the skin helps protect against some of this damage. Long-term UV exposure can lead to eye disorders and skin cancers, such as melanomas and non-melanoma types like basal and squamous cell carcinomas. Other types of light, like IR and visible light, can also harm the skin. However, sun

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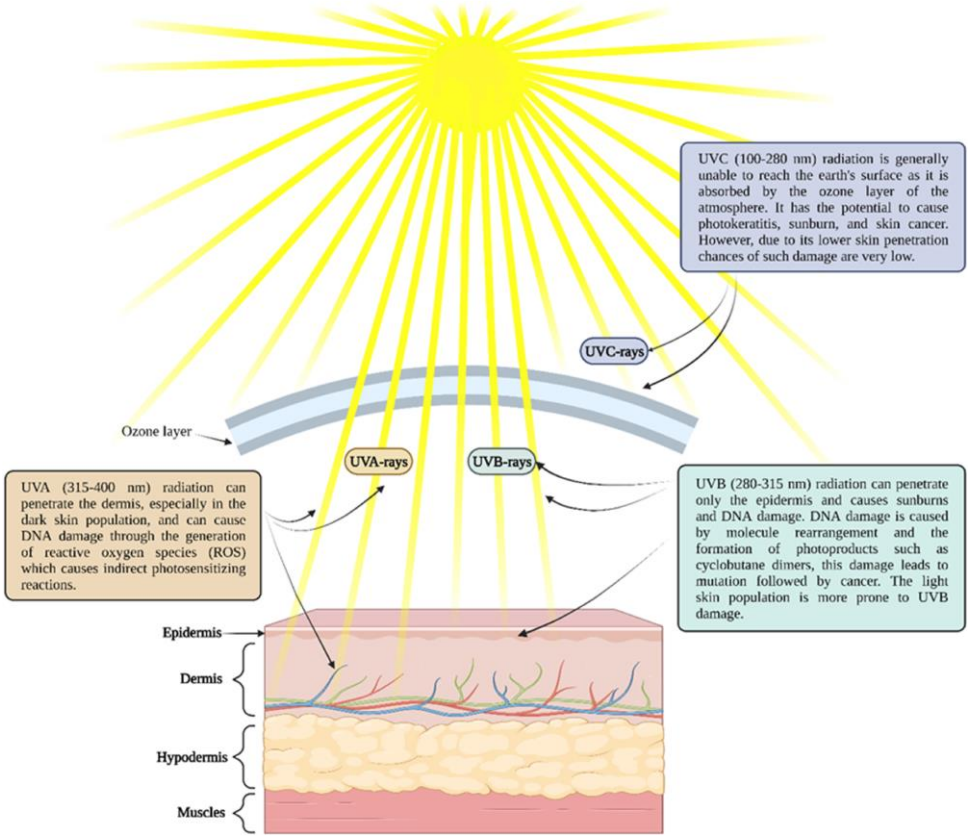
exposure has benefits, like improving heart health and producing vitamin D. To protect against the harmful effects of the sun, use sunscreen, wear protective clothing, and avoid direct sun exposure. Sunscreens, when used regularly, can reduce the risk of skin cancer and premature aging. UV sensitivity varies with skin colour, and darker skin has more protection, but can still suffer from UV damage. Therefore, sunscreen is important for everyone.



Solar UVR:

UVB and UVA are the main types of UV radiation from the sun, and we are usually exposed to them regularly. UV radiation intensity varies based on factors like location, time of day, and season. UVB is strongest during the summer and between 11 a.m. and 3 p.m., while UVA intensity is more constant throughout the day and year. Weather conditions like clouds, pollution, and temperature can also affect UV radiation levels. In developed countries, most people are exposed to UV radiation in short bursts, especially on their face, neck, and hands, due to daily activities. This incidental exposure can make up 80-90% of total yearly UV exposure and is linked to over 60% of nonmelanoma skin cancers (NMSC) that appear on these areas.

Effects of Solar UVR on the Skin (Descriptive):

1. **Short-term Effects of UVR:** Exposure to UV radiation from the sun can lead to immediate skin reactions, often referred to as acute effects. These include:

- **Sunburn (inflammation):** UVB radiation causes redness, pain, and inflammation on the skin, known as sunburn. This is a common response to overexposure to the sun.
- **Skin Darkening (Tanning):** UVA radiation causes the skin to darken, a process called

tanning. While it might seem harmless, this is a sign of skin damage.

- **Skin Thickening (Hyperplasia):** The skin's outer layers may become thicker as a protective response to UV exposure, which is known as hyperplasia.
- **Weakened Immune Response (Immunosuppression):** UV radiation can suppress the skin's immune system, making it more vulnerable to infections and other damage.
- **Vitamin D Production:** UVB radiation helps the skin produce vitamin D, which is essential for bone health and other functions.

2. **Long-term Effects of UVR:** Prolonged or repeated exposure to UVR can cause serious long-term damage, leading to:

- **Skin Cancer (Photocarcinogenesis):** UV radiation is a major contributor to the development of skin cancers. The most common forms are nonmelanoma skin cancers (NMSC) and malignant melanoma.
- **Premature Skin Aging (Photoaging):** Chronic exposure to UV radiation accelerates the aging process of the skin, causing wrinkles, loss of skin elasticity, dryness, and other visible signs of aging.

3. **UVR and Skin Cancer:** UVR plays a significant role in the development of skin cancers, especially nonmelanoma skin cancers (NMSC), which include basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). Several factors contribute to this:

- **Genetic Sensitivity:** People with conditions like **xeroderma pigmentosum**, a genetic disorder that prevents proper DNA repair, are extremely sensitive to UVR and develop skin cancers at an early age, mainly on sun-exposed areas of the body.
- **Higher UVR Exposure in Certain Areas:** The incidence of NMSC is higher in areas of the body that receive frequent sun exposure, such as the face, neck, arms, and hands.
- **Skin Type and Sunburn Risk:** People with lighter skin types (Fitzpatrick skin types I and II) who burn easily are more vulnerable to developing NMSC due to their skin's lower tolerance to UV radiation.
- **Genetic Mutations:** Exposure to UVR causes mutations in the **p53 tumor suppressor gene**, which is found in 90% of squamous cell carcinomas and 50% of basal cell carcinomas. These mutations are often linked to UVR exposure.

4. **UVR and Malignant Melanoma:** Unlike nonmelanoma skin cancers, the link between UVR exposure and malignant melanoma (the most dangerous form of skin cancer) is more complex. However, there is strong evidence suggesting UVR plays a role in melanoma development, particularly:

- **Severe Sunburn in Childhood:** Studies show that severe sunburns during childhood can increase the risk of developing melanoma later in life.
- **Skin Sensitivity:** People with fair skin, light eyes, and hair, who are more prone to sunburn, are at a higher risk of melanoma due to their skin's lower ability to protect itself from UV radiation.
- **Different Mechanisms for Melanoma:** Interestingly, UVB-related mutations in the p53 gene are not commonly found in

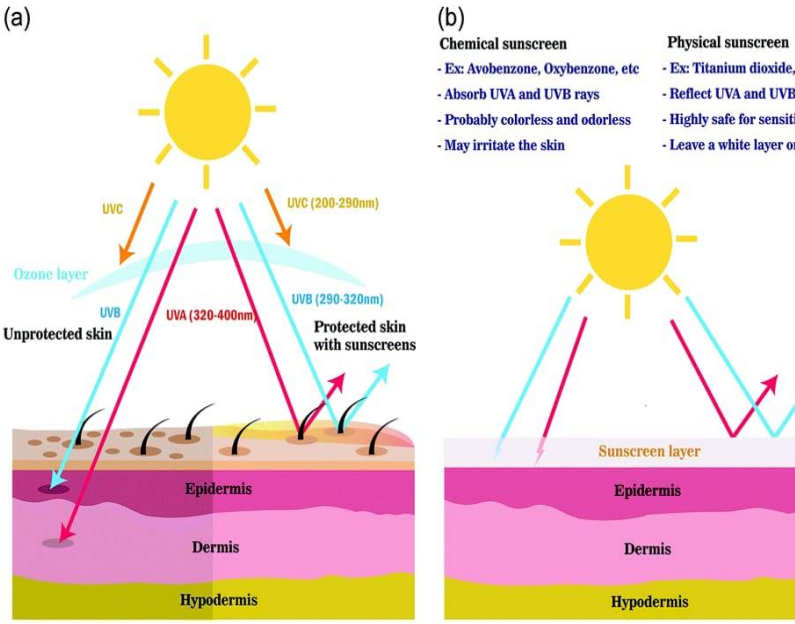
melanomas, suggesting that the mechanisms leading to melanoma may differ from those of nonmelanoma skin cancers.

5. **UVR and Photoaging:** Chronic exposure to UVR doesn't just cause skin cancer; it also leads to photoaging, which is the premature aging of the skin due to sun exposure. The signs of photoaging include:

- **Skin Texture Changes:** Skin may become rough, dry, and less smooth as collagen and elastin fibres are damaged by UV radiation.
- **Irregular Pigmentation:** Freckles and dark spots (lentigenes) may appear, and existing age spots can become more prominent.
- **Wrinkling and Loss of Elasticity:** UV exposure breaks down the skin's collagen and elastin, leading to the development of wrinkles, sagging, and overall loss of skin firmness.
- **Increased Risk in Fair Skin:** People with fair skin who have had excessive sun exposure tend to show more severe signs of photoaging compared to those with minimal sun exposure.
- **Reversible with Protection:** While photoaging is different from natural skin aging (chronological aging), it can be slowed or reversed with proper UV protection, such as using sunscreen, wearing protective clothing, and limiting sun exposure. Treatments like retinoids (all-trans-retinoic acid) can also help reduce signs of photoaging.

Mechanism Of Action of Sunscreen:

Sunscreens are designed to protect the skin from harmful ultraviolet (UV) radiation from the sun. They work by either absorbing or reflecting UV rays to prevent them from reaching the skin.



The key mechanisms of action of sunscreens are as follows:

1. UV Absorption:

- **Chemical (Organic) Sunscreens:** These sunscreens contain active ingredients that absorb UV radiation and convert it into harmless heat, which is then released from the skin. The active ingredients in chemical sunscreens, such as avobenzone, oxybenzone, and octinoxate, are designed to absorb UV rays in the **UVA** and **UVB** ranges.
- **How it works:** When UV radiation hits the skin, the sunscreen ingredients absorb the UV rays, preventing them from penetrating deeper into the skin layers and causing damage such as sunburn, premature aging, or skin cancer.

2. UV Reflection and Scattering:

- **Physical (Inorganic) Sunscreens:** These sunscreens contain mineral ingredients like **zinc oxide** and **titanium dioxide** that act as physical barriers. These minerals sit on the skin's surface and reflect or scatter UV radiation away from the skin.

- **How it works:** Zinc oxide and titanium dioxide reflect UV rays, particularly **UVA** and **UVB**, from the skin. This creates a protective layer on the surface that prevents UV radiation from penetrating the skin and causing damage.

3. Broad-Spectrum Protection:

- **Combination of Chemical and Physical Filters:** Many sunscreens contain a combination of chemical and physical ingredients to provide protection against both **UVA** and **UVB** radiation. While chemical sunscreens primarily target UVB, physical sunscreens provide broad-spectrum protection by reflecting both UVA and UVB radiation.

- **UVA Protection:** UVA rays penetrate deeper into the skin, causing aging (photoaging), DNA damage, and increasing the risk of skin cancer. Sunscreens with ingredients like **avobenzone**, **ecamsule**, or **Mexoryl** provide effective UVA protection.

- **UVB Protection:** UVB rays are responsible for sunburn and can directly damage DNA, leading to skin cancer. Sunscreens with ingredients like **octinoxate**, **octocrylene**, and **homosalate** protect the skin from UVB exposure.

Challenges and Limitations of Current Sunscreens:

Limited UV Filters:

Only titanium dioxide and zinc oxide are recognized as safe and effective by the FDA. Many other UV filters need more safety data, leading to limited choices for consumers in the US.

Skin Appearance Issues:

Mineral sunscreens (zinc oxide, titanium dioxide) can leave a white residue, which is disliked, especially by those with darker skin.

Environmental Concerns:

Some sunscreen ingredients, like oxybenzone and octinoxate, are harmful to coral reefs. Certain places, like Hawaii, have banned these ingredients to protect the environment.

Systemic Absorption:

Ingredients like oxybenzone and octinoxate are absorbed into the body, raising safety concerns, though studies have not found clear evidence of harm.

Benzene Contamination:

Some sunscreen products have been found to contain harmful levels of benzene, a carcinogen. This contamination is believed to be caused by manufacturing issues.

Slow Approval of New Filters:

The FDA has not approved new sunscreen filters in over a decade, limiting the availability of better and more effective sunscreen options available in other countries.

Concerns Regarding Sunscreen Safety:

1. **Hormonal Effects of Sunscreen Chemicals:**

   - **Benzophenones**: Previously common in sunscreens, but studies found it in human urine and breast milk. It may disrupt hormones like estrogen and testosterone, potentially affecting development and reproduction in animals.

   - **Camphor derivatives**: These are used in sunscreens to absorb UV rays but can build up in the body. They may affect hormone levels,

especially estrogen and progesterone, based on animal studies.

- **Cinnamates (e.g., octyl methoxycinnamate)**: Widely used in sunscreens to block UV rays, but they may disrupt hormones such as estrogen, progesterone, and thyroid hormones.

2. **Masking Sunburn Damage with Anti-inflammatory Ingredients:**

- Some sunscreens contain anti-inflammatory chemicals (e.g., oxybenzone, homosalate) that reduce redness (sunburn), but they don't necessarily prevent deeper skin damage. This could give users a false sense of security, as they may think they are fully protected when they may not be.

- A sunscreen may hide the visible signs of sunburn but still allow skin damage at the cellular level, which could increase the risk of skin cancer over time.

3. **Vitamin A Derivatives and Antioxidants:**

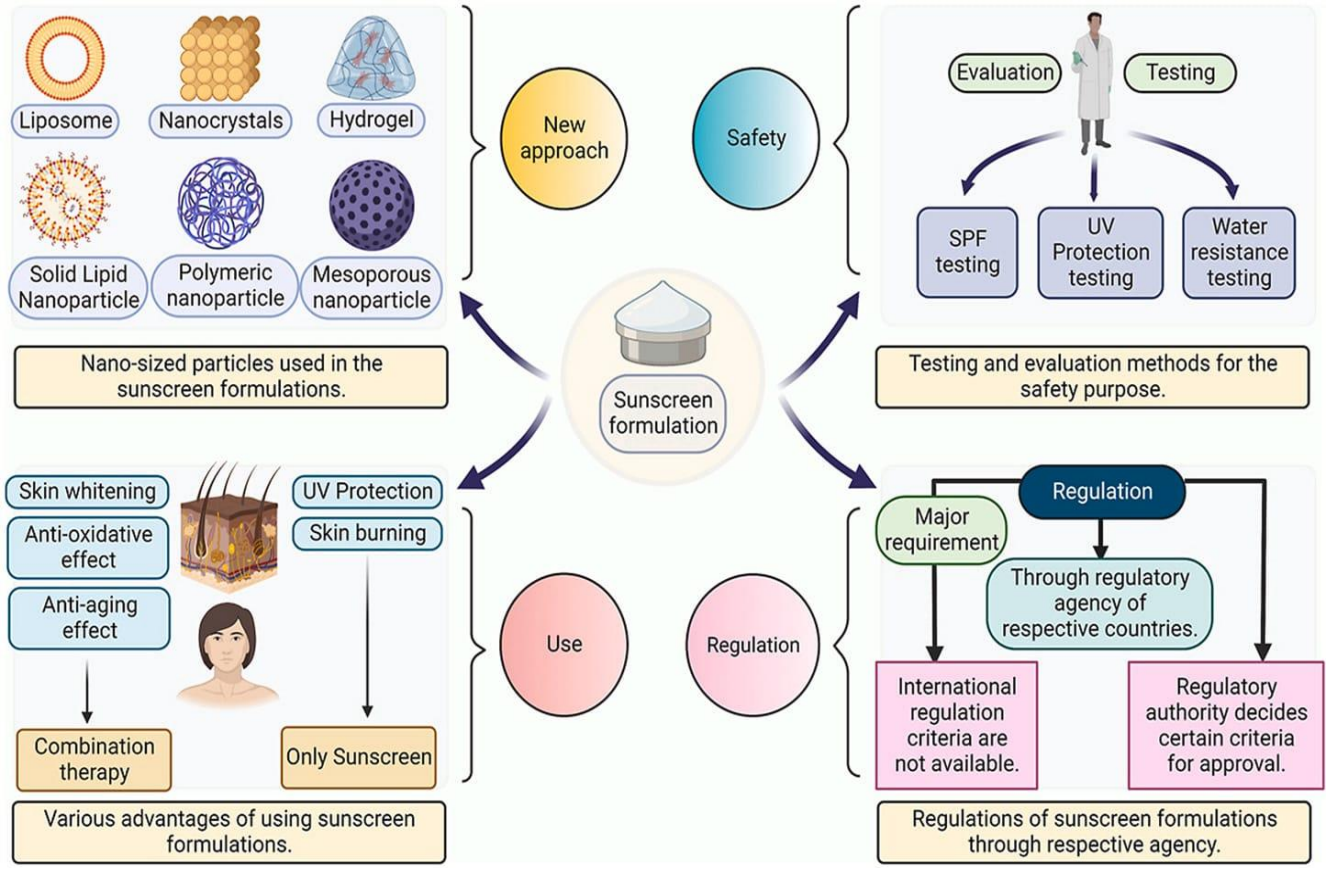
- Sunscreens sometimes contain **vitamin A derivatives** (like retinols) and antioxidants (like caffeine or echinacea). While antioxidants are meant to protect the skin from free radicals, some research suggests that vitamin A in sunscreens may increase the risk of skin cancer when exposed to UV rays, as UV light can break down antioxidants and create harmful by-products.

4. **Issues with UVA Filters:**

- In the US, only **zinc oxide** and **titanium dioxide** are approved as physical UVA filters. These are found in mineral sunscreens. However, **avobenzone** is a common chemical filter in non-mineral sunscreens but breaks down when exposed to UV light. To prevent this, it's often mixed with other chemicals like **octocrylene**, which also has some safety concerns.

5. **Ongoing Safety Concerns:**

- Many of these issues, like hormonal effects, have mostly been demonstrated in animal studies. However, public concern is growing, and more research is needed to fully understand the safety of sunscreen ingredients, especially as they relate to human health and long-term effects.



Regulatory Aspects of Sunscreens (Simplified)

Importance of Sunscreens for Skin Cancer Prevention:

Sunscreens are important for preventing skin cancer by protecting against UV rays. Regulations for sunscreens focus more on public health than just testing. For example, tanning salons have been banned in many places because of their harmful effects. Research from the UK shows that if someone with fair skin uses a poor-quality sunscreen, just a two-week vacation in the tropics could expose them to as much UVA radiation as visiting a tanning salon 10 times!

Clinical Effectiveness of Sunscreens:

To really prove that a sunscreen works, it should reduce biological effects that lead to skin cancer, such as DNA damage, weakened immune systems, and free radicals. However, these biological studies are often not done because they are expensive and difficult. So, how are sunscreens usually tested?

1. In Vivo Testing (Testing on Humans)

. Sun Protection Factor (SPF) Testing

- **Purpose**: To measure how well a sunscreen protects against UVB radiation, which causes sunburn.
- **Method**:
  - Sunscreen is applied to a small area of human skin.
  - The skin is exposed to UVB radiation, and the amount of UV exposure needed to cause erythema (redness or sunburn) is recorded.

- The SPF is determined by comparing the amount of UV exposure required to cause erythema on the protected skin versus unprotected skin.

2. UVA Protection Testing

- **Purpose**: To assess how well a sunscreen protects against UVA rays, which penetrate deeper into the skin and contribute to skin aging and DNA damage.
- **Method**:
  - Sunscreen is applied to human skin, and the skin is exposed to UVA radiation.
  - The **Persistent Pigment Darkening (PPD)** method is commonly used, where the degree of skin pigmentation is measured after exposure to UVA light.
  - **Critical Wavelength (CW)** testing can also be done, where the sunscreen's ability to block both UVA and UVB radiation is tested to evaluate broad-spectrum protection.

3. Photostability Testing

- **Purpose**: To evaluate whether the sunscreen maintains its protective ability when exposed to sunlight or artificial UV light.
- **Method**:
  - The sunscreen is applied to the skin and exposed to UV radiation.
  - Researchers then measure any degradation or loss of effectiveness in the sunscreen's active ingredients after exposure to sunlight.

4. Water Resistance Testing

- **Purpose**: To determine how well the sunscreen performs in wet conditions (e.g., sweating or swimming).
- **Method**:
  - Sunscreen is applied to the skin, and the individual undergoes activities that simulate sweating or immersion in water (e.g., swimming).
  - After exposure to water, the sunscreen is tested to see if it still provides effective protection.

5. Irritation and Sensitization Testing

- **Purpose**: To check if the sunscreen causes skin irritation or allergic reactions.
- **Method**:
  - Sunscreen is applied to a small patch of skin (patch test) for 48-72 hours to observe any irritation or allergic reactions (redness, swelling, itching).

6. Erythema Testing (Sunburn Testing)

- **Purpose**: To measure how well a sunscreen prevents sunburn (redness) caused by UV exposure.
- **Method**:
  - Sunscreen is applied to an area of skin, and the skin is exposed to UV radiation.
  - The erythema (sunburn) is observed and measured over the next 24-48 hours to assess how well the sunscreen prevented sunburn.

7. Long-Term Skin Health and Cancer Prevention Testing

- **Purpose**: To evaluate whether sunscreen can prevent long-term skin damage, such as photoaging and skin cancer.
- **Method**:
  - Individuals use sunscreen over an extended period while being exposed to controlled UV radiation.
  - Skin health, signs of aging, and the occurrence of skin cancer are observed and documented.

2. **In Vitro Testing (Testing Outside the Body)**

1. Sun Protection Factor (SPF) Testing

- **Purpose**: To measure how well a sunscreen protects against UVB rays, which are responsible for sunburn.
- **Method**:
  - A small amount of sunscreen is applied to human skin or artificial skin samples.
  - The skin is then exposed to UVB radiation to determine the minimum amount of sunscreen needed to prevent sunburn.
  - The SPF value is calculated by comparing the amount of UV radiation required to produce redness (erythema) on protected skin versus unprotected skin.

2. UVA Protection Testing

- **Purpose**: To assess how well a sunscreen protects against UVA rays, which penetrate deeper into the skin and contribute to aging and DNA damage.
- **Method**:
  - UVA protection can be tested using **in vitro UVA tests** such as the **Persistent Pigment Darkening (PPD)** method, which measures the sunscreen's ability to protect against UVA-induced pigmentation changes.
  - Sunscreen is applied to artificial skin or test models and exposed to UVA light to measure the degree of protection.
  - The **Critical Wavelength** (CW) test is also used to determine the broad-spectrum UVA protection offered by a sunscreen.

3. Stability and Photostability Testing

- **Purpose**: To determine if the sunscreen remains effective when exposed to sunlight and over time.
- **Method**:
  - Sunscreens are exposed to artificial UV light in a controlled setting to simulate sun exposure.
  - The product's active ingredients are analyzed for any degradation or loss of effectiveness.
  - This helps identify if the sunscreen remains stable and effective after prolonged sun exposure.

4. Irritation and Sensitization Testing

- **Purpose**: To evaluate whether a sunscreen causes skin irritation or allergic reactions.
- **Method**:
  - **Patch tests** using cultured skin cells or reconstructed human skin models are conducted to evaluate any irritation potential of the sunscreen.

- Sensitization tests involve applying the sunscreen to the skin to check for allergic reactions over time.

5. Antioxidant Activity Testing

- **Purpose**: To assess whether the sunscreen has antioxidant properties that help neutralize free radicals produced by UV exposure.
- **Method**:
  - Various assays, like the **DPPH assay** or **ABTS assay**, are used to measure antioxidant capacity in sunscreen formulations.
  - These tests show how well the sunscreen prevents oxidative stress, which can lead to skin damage.

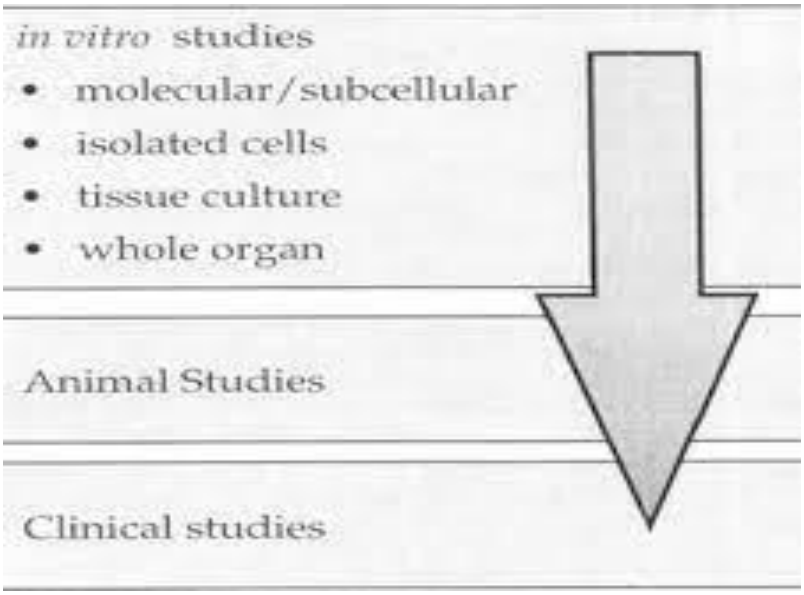


Fig. Toxicological hierarchy in assessment of human risk.

SPF Value of Sunscreen

The SPF value (Sun Protection Factor) of a sunscreen provides information on how well it protects the skin from UVB radiation, the type of ultraviolet light primarily responsible for sunburn and contributing to skin cancer. Here's a comprehensive look into how SPF works, its interpretation, and what to consider when selecting sunscreen based on its SPF value.

$$\text{SPF} = \frac{Time\ taken\ by\ skin\ to\ burn\ with\ sunscreen}{Time\ taken\ by\ skin\ to\ burn\ without\ suncreen}$$

What Does SPF Mean?

SPF is a measure of how effectively a sunscreen protects against UVB rays, which cause sunburn and damage skin cells. The higher the SPF number, the more protection the sunscreen offers. Specifically, SPF indicates how much longer a person can stay in the sun without getting sunburned when using sunscreen compared to if they weren't using sunscreen.

Type of Protection	SPF Value
Minimal	1-4
Moderate	4-6
Extra	6-8
Maximal	8-15
Ultra	>15

SPF Protection Breakdown:

The SPF number is a ratio of the amount of UVB radiation that causes sunburn to the amount of UVB radiation that reaches the skin when sunscreen is applied. The formula used to calculate SPF is based on how long it takes for the skin to burn with sunscreen on versus how long it would take to burn without any sunscreen.

SPF 15: Blocks approximately 93% of UVB rays.

SPF 30: Blocks about 97% of UVB rays.

SPF 50: Blocks about 98% of UVB rays.

SPF 100: Blocks about 99% of UVB rays.

How SPF is Tested:

Sunscreens are tested on fair-skinned individuals who are exposed to UV light in a controlled setting to determine how long it takes for them to burn with and without sunscreen. SPF is calculated by comparing the time it takes for someone to get sunburned with sunscreen on to the time it would take to burn without protection. Challenges and Limitations of Sunscreen safety and efficacy:

Safety Issues:
1.Chemical absorption: Some chemical UV filters (e.g. Oxybenzone) may penetrate the skin and enter the blood stream, raising concerns about hormonal disruption.
2.Environmental impact: Certain ingredients contribute to coral reef bleaching and aquatic pollution.
3.Skin irritation and allergy: Some sunscreen ingredients (fragrances, preservatives, chemical filters can cause allergic reaction or irritation.)
4.Stability and Degradation: Some ingredients breakdown when exposed to sunlight, reducing effectiveness.

Efficacy Issue:
Incomplete UV protection: Many sunscreens focus more on UV B protection (SPF) and may not provide sufficient UV A protection.
Application issues: People often apply to little sunscreen or misareas, reducing effectiveness.

Water and sweat Resistance: Water-resistance formulas still time and require frequent reapplication.
Misleading SPF ratings: High SPF can give a false sense of security leading to longer sun exposure without applying.

Safety of Sunscreen Ingredients:

UV Filter	Type	UV Protection	Common Usage	Notes
Zinc Oxide	Mineral	UV-A & UV-B	Broad spectrum	Gentle on skin, reef-safe
Titanium dioxide	Mineral	UV-B & some UV-A	Broad spectrum	Non-irritating, good for sensitive skin
Avobenzone	Chemical	UV-A	Sunscreen	Often combined with other filters for stability
Oxybenzone	Chemical	Both UV-A & UV-B	Sunscreen	Controversial due to environmental concerns
Octin oxate	Chemical	UV-B	Sunscreen, cosmetic	May degrade with sun exposure
Octocrylene	Chemical	UV-B & Some UV-A	Sunscreen, moisturizer	Helps stabilize other uv filter
Homosalate	Chemical	UV-B	Sunscreen	Often used with other filter
Tinosorb S	Chemical	UV-A & UV-B	European & Asian sunscreen	Broad spectrum , photostable

Sunscreen regulations vary by country but generally focus on safety, efficacy, and labeling requirements:

United States (FDA): Sunscreens are considered over-the-counter drugs, regulated for safety and efficacy. They must be tested for SPF and broad-spectrum protection (UVA and UVB). Ingredient safety is reviewed, with some under ongoing scrutiny (e.g., oxybenzone).

European Union (EC Cosmetics Regulation): Sunscreens must meet strict safety and efficacy standards, including SPF and UVA protection. Only approved ingredients are allowed, and products must include clear labeling and water-resistance claims. Environmental concerns are also addressed, with some ingredients banned due to coral reef damage.

Australia (TGA): Sunscreens are regulated as therapeutic products, requiring rigorous SPF and broad-spectrum testing. Ingredient approval is strict, and products must include clear labeling and water-resistance information.

Canada (Health Canada): Sunscreens are regulated as drug products, requiring testing for SPF, broad-spectrum protection, and ingredient safety. Water resistance claims must be substantiated.

Japan: Sunscreens are classified as quasi-drugs, requiring SPF testing, ingredient approval, and water-resistance claims. Globally, there is growing emphasis on environmental safety, with some regions banning harmful ingredients to protect marine ecosystems.

Suncreen formulations by different companies with their main characteristics:

Brand	Product Name	Key Characteristics
ELTAMD	UV daily broad-spectrum SPF 46	Combines sun protection with hyaluronic acid for moisturizing
Hero cosmetics	Force shield superlight sunscreen SPF 30	Non-comed ogenic,prevent breakouts, suitable for sensitive skin.
Aveeno	Protect + Hydrate Sunscreen body Lotion SPF 60	High SPF protection with a non-greasy ,water-resistant formula ; ideal for outdoor activities.
La Roche -Posay	Anthelios Mineral Suncscreen	Minerak based formula providing effective UV protection without irritating sensitive skin.
Cetaphil	Daily Oil-Free Facial Moisturizer with SPF 35	Combines sun protection with moisturizing benefits ; suitable for oily skin.
Colorescience	Total Protection Brush -on shield SPF 50	Convenient brush on application ; offers broad spectrum protection and is water -resistant.
Skin Ceuticals	Physical Fusion UV Defence SPF 50	Tinted broad spectrum protection with added antioxidants ; suitable for sensitive skin.
Glossier	Invisible Shield SPF 35	Light weight , gel-based formula that leaves no residue; ideal for daily wear.

Best Practices for Sunscreen Use

✅ **Proper Application:**

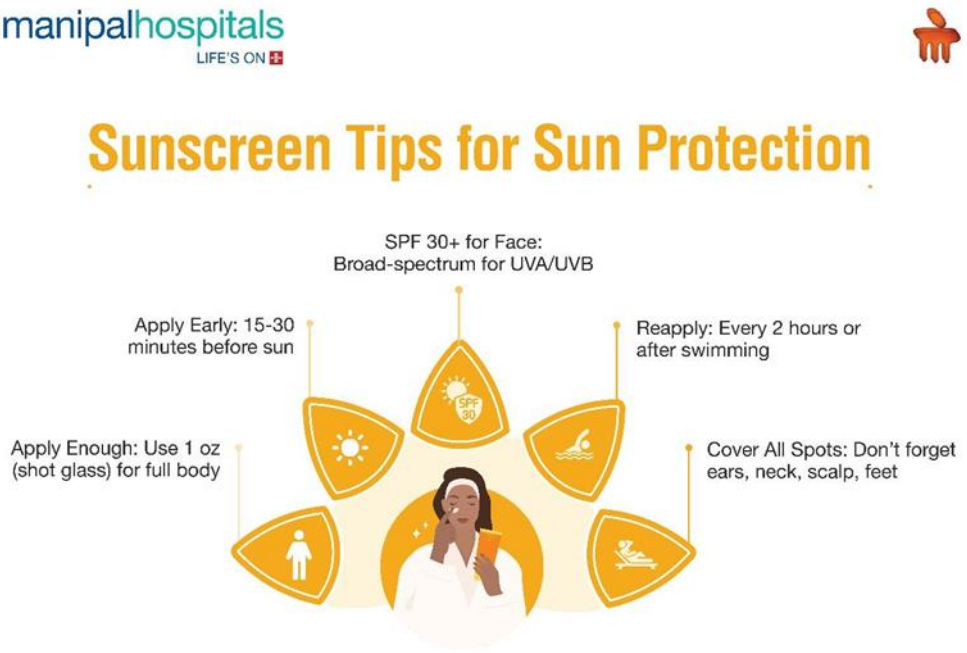
- Use broad-spectrum SPF 30+, apply 15-30 mins before sun exposure.
- Use a nickel-sized amount for the face, a shot-glass amount for the body.
- Cover ears, neck, hands, feet, and lips (SPF lip balm).

✅ **Reapply Regularly:**

- Every 2 hours, or immediately after swimming, sweating, or towel drying.
- Check for expiration dates to ensure effectiveness.

✅ **Combine with Other Protection:**

- Wear hats, sunglasses, and UV-protective clothing.
- Seek shade between 10 AM – 4 PM when UV rays are strongest.
- Use sunscreen daily, even on cloudy days and indoors.



CONCLUSION:

In conclusion, the safety and efficacy of sunscreens are critical components in their role in protecting against harmful UV radiation and reducing the risk of skin damage, premature aging, and skin cancer. Modern sunscreens, with a combination of physical and chemical filters, offer broad-spectrum protection when applied correctly and in adequate amounts. However, there are concerns about potential adverse effects of certain ingredients, such as oxybenzone and avobenzone, which have raised questions about endocrine disruption and environmental impact. Despite these concerns, the benefits of sunscreen in preventing skin damage far outweigh the risks when used as part of a comprehensive sun protection strategy, including protective clothing and seeking shade. Ongoing research and regulatory evaluations are essential to continue improving sunscreen formulations to enhance their safety, efficacy, and environmental sustainability. Thus, individuals should be encouraged to use sunscreen consistently while staying informed about the latest developments in sunscreen safety.

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