Analysis of the situation and trends in sunscreen products

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Abstract

Solar radiation has played a key part in the evolution of human beings. Vitamin D, whose synthesis is related to exposure to solar radiation, is vital for the development of human bone. On the other hand, melanin is our natural sunscreen as it is capable of physically and chemically filtering the detrimental effects of UV radiation; it absorbs UV rays, making them lose energy, and neutralizes the chemical products (free radicals) that form in the skin after exposure to the harmful effects of the sun.

Although our organism contains intrinsic photoprotection control mechanisms, we learn more every day about the adverse effects of solar radiation on our skin, visible (erythema) as well as invisible (photo immunosuppression, photo carcinogenesis, photo ageing); the latter are initially hidden reactions with harmful consequences for our health.

The current challenge and the future of the development of new sunscreen products, lies in the incorporation of highly effective protection factors in their formulation, offering protection not only from UVB rays (which cause redness) and UVA rays (responsible for cellular ageing), but from the entire spectrum of ultraviolet radiation, which is known as spectral homeostasis.

Furthermore, the industry is dealing with consumers who are better informed and more demanding, who are looking for effective products that can satisfy their needs. The incorporation of innovation in the development of photoprotectors is changing the trend that the greatest percentage of sales of this type of products is recorded in summer and is converting them into a basic need, as more people use sun protection all year round.

Introduction

Solar Radiation

Solar radiation includes, among other things, ultraviolet radiation, visible light and infrared radiation[1].

- Infrared radiation is primarily responsible for the heat effect of solar radiation. About 50% of this radiation is capable of reaching the earth's surface.
- Visible radiation provides light energy, which stimulates the human retina and creates the sensation of vision. It also provides chemical and heat energy, though to a lesser degree than infrared radiation.
- Ultraviolet radiation contains the greatest amount of energy of the three, due to its shorter wavelength. UV radiation is subdivided into three different wavelengths, ranging from shorter to longer: UVC, UVB and UVA; the latter is subdivided into UVA II and UVA I. UVC rays are absorbed by the ozone layer and do not reach the earth's surface.

The wavelength and energy of the different types of radiation determine the damage they do to our skin.

Of all these types of radiation, we know most about the etiology of the damage ultraviolet radiation can cause to our skin. UVB radiation, which has a shorter wavelength, is capable of penetrating into the epidermis (the outermost layer of the skin) and a mere 10% of the dermis, whereas UVA radiation, which has a longer wavelength, penetrates mainly into the dermis.

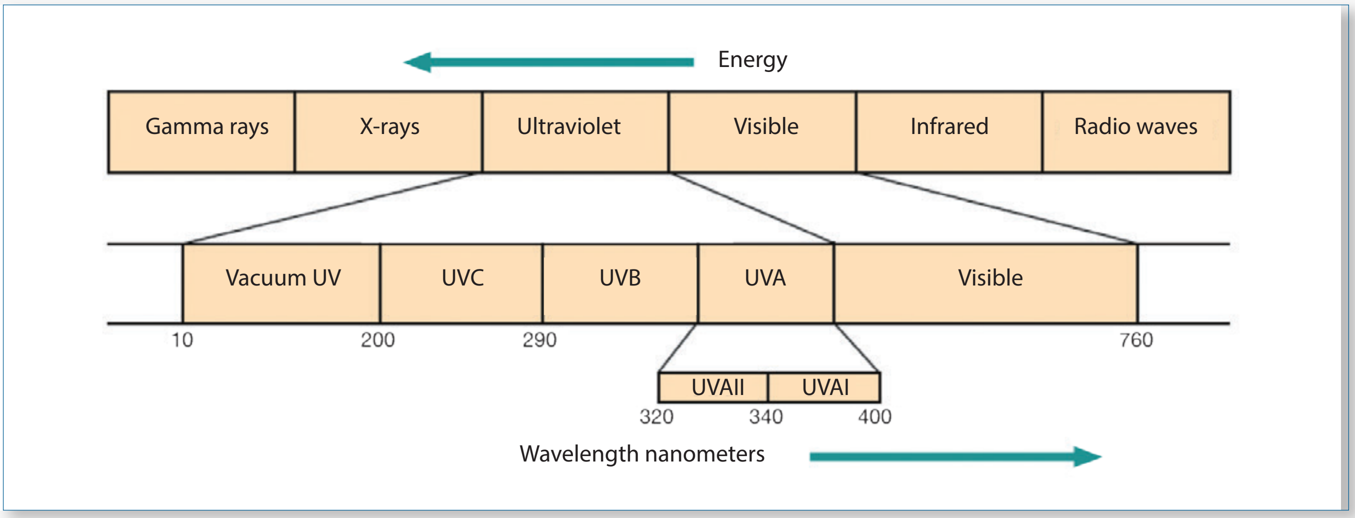

Figure 1. Electromagnetic spectrum divided into the major regions of wavelength. (Taken from Fitzpatrick. Dermatology in General Medicine)

Among the damaging effects these types of radiation have on the skin, there are visible effects, even after a few hours of exposure, such as erythematous reactions, redness of the skin due to unprotected or excessive exposure to the sun, mainly caused by UVB rays, and pigmentation, for which UVA rays are mostly responsible. However, UV radiation also has some "invisible effects" which in the long term are far more detrimental to our health; this type of radiation is involved in processes of photo immunosuppression, photo carcinogenesis and photo ageing.

Photo immunosuppression and photo carcinogenesis

UV radiation causes direct damage to our immune system; it inhibits the number and migration of Langerhans cells, which exercise a key function as antigen-presenting cells to the immune system, it causes tolerance to Helper T lymphocytes (CD4+), inhibits interferon production and diminishes the production of adhesion molecules (I CAM -1) by keratinocytes, among other changes. This gives rise to a delayed hypersensitivity reaction of our immune system.

Apart from this direct damage, it also causes alterations that indirectly affect the immune system, particularly photo oxidative stress reactions, which involve higher concentrations of free radicals (ROS), which cause functional and structural deterioration of the cell elements (proteins, lipids and carbohydrates) and generate DNA photoproducts. This molecular DNA alteration can lead to the transformation of a healthy cell into a cancerogenous one, which cannot be detected by the immune detecting network formed by the Langerhans cells, as those have also been damaged. Therefore, such a cell will be able to develop without any impediment, triggering the development of a type of skin cancer, ranging from basal cell and squamous cell carcinomas to melanomas.

One significant fact is that local immunosuppression is produced with lower doses of UV radiation than those responsible for causing erythema. Thus, skin redness, which previously was seen as the main problem associated with solar radiation, has now become the visible alarm signal showing that the immuno suppression process has already started and, consequently, the possibility of developing photo carcinogenesis.

Photo ageing

Type 1 collagen is the main structural protein in the dermal extracellular matrix. The precursor molecules to collagen, procollagen, are synthesized in the dermal fibroblasts. Procollagen is secreted into the extracellular space where it matures enzymatically and is transformed into collagen.

UV radiation causes alterations to dermic collagen at two levels:

1. Stimulation of the degradation of collagen, generating fragmented and disorganized collagen. This causes a massive accumulation of abnormal elastin, known as "solar elastosis", which can be defined as an accumulation of solar scarring which visibly translates into wrinkles.

2. Inhibition of procollagen synthesis, which results in a loss of dermal collagen content. One single exposure to UV radiation (2MED) is responsible for an almost total loss of procollagen synthesis, which lasts for 24 hours, followed by a recovery period of 48-72 hours after exposure.

The etiology of this damage is related to metalloproteinases , proteins of the extracellular matrix, responsible for the degradation of collagen and the reconstruction of damaged collagen. Vastly increased numbers of these proteinases have been recorded (up to millions above their base level). In increased numbers, they cause an exacerbated degradation of collagen; moreover, they are incapable of reconstructing damaged collagen, the result of which is solar elastosis.

Trends and Innovations

Spectral homeostasis

The earliest sunscreen products were developed in the first half of the last century, as a response to the need to alleviate sunburn related to tanning. The evolution in studies on the harmful effects of the entire spectrum of UV radiation, above all in relation to skin cancer, led to a demand for sunscreens that protected from the entire UVA spectrum. The first UVA filters appeared in the 1980s, while broad spectrum filters were created around the turn of the century. But, what kind of protection should the ideal sunscreen product offer? A photo protector should offer an essentially uniform protection from the entire ultraviolet spectrum. In 1991, it was Diffey who coined the term spectral homeostasis, to refer to this concept of uniformity.

The main characteristic of a sunscreen product that offers spectral homeostasis is the fact that the amount of UV radiation our skin receives is attenuated, while the quality of the UV spectrum remains unchanged; there is no UVB-biased protection spectrum.

Over the last two decades, efforts to improve UVA protection and reach the ultimate goal of spectral homeostasis have been tremendously successful. The European recommendation for protection from UV radiation provided a significant milestone, which is met in almost all sunscreen products in Europe. However, many of the daily care products that include UV filters do not comply with this minimum requirement for UVA protection. Nowadays, the use of daily care products with sunscreens that only provide protection from UVB does not offer added value in terms of sun protection.

Ultimately, spectral homeostasis should be one of the features of the sunscreens of the future, as well as of daily care products, in particular anti-ageing products.

Specific Photoprotectors for every need

The incorporation of new textures has introduced time saving products which can be applied more quickly, as well as easy to use products, with simple and user-friendly application methods. Examples of these are sprays for use on wet skin, in-shower aftersun, or transparent sprays.
It is important to take into account the market segmentation of this type of products, which vary according to the target group they are aimed at. With reference to sunscreen products for paediatric use, sun damage has a greater and accumulative effect on children, as their natural protection

system has not been fully developed, which is why adequate protection from childhood will reduce the risk of developing cancer in adulthood. As for male consumers, the aim is to create a photoprotector with different organoleptic qualities, such as a less oily texture. There is also a great demand for protectors targeted at sports people, who are exposed to high levels of solar radiation and tend to sweat profusely. Whereas in pregnant women, sun protection not only helps protect them from premature ageing and skin cancer, but can also alleviate pregnancy- related skin problems, such as pigmented spots that appear on the skin. Finally, the boom in the consumption of bio or natural products has also affected these products, which have seen an increased trend towards products without chemical substances, mineral sun filters and products manufactured with natural ingredients, or inspired by nature.

Special mention should be made of specific photoprotectors for particular skin types, such as atopic skin conditions, which require extra hydration; or couperose-prone skin, which is extremely sensitive and needs very high protection, combined with a soothing effect.

Differentiating according to the body zone the product is intended for, the widespread use of protective lip care with SPF stands out; as well as the use of products designed for a specific location. For instance, there are sunscreen sticks for the protection of extremely sensitive areas such as scars, or very specific areas, like moles or tattoos, the latter of which lose colour or precision when exposed to the sun, where it is advisable to protect and hydrate at the same time. Likewise, there are hair care products with sun protection, designed to keep hair glossy and healthy.

Regulations and studies to support the claims of sunscreen products

There are different methodologies to determine the degree of protection from ultraviolet radiation, which can be carried out through "in vivo" or "in vitro" studies. It is recommended to follow the applicable regulation according to the country chosen for the placing on the market of the product.

To determine the sun protection factor (SPF), European regulations are guided by the international standard ISO 24444:2010 . This is an "in vivo" clinical trial in which the study subjects with phototypes I, II and III are subjected to controlled radiation with a Xenon arc lamp solar simulator. Various areas of untanned skin on the back are radiated, after applying 2 mg/cm2 of sunscreen on an area of 35 cm2, with the objective of inducing the minimal erythemal dose (MED) within 24 hours of exposure. The sun protection factor (SPF) is defined as the ratio between the minimal erythemal dose on sunscreen-protected skin and the MED on unprotected skin.

Currently, to verify UVA protection at European level, following the international standards ISO 24443:2012 or ISO 24442:2011 (UVA-PF), which respectively use an experimental "in vitro" and "in vivo" approach, is recommended.

The claims that can be included in the sunscreen are determined by the methodology that was used to verify the protection they offer. Table 2 shows different ways of claiming protection from UVA, depending on the country and the method used .

An extremely important property sunscreens can have and which is related to its efficacy, is water resistance. The design of these studies at European level is carried out in compliance with the Colipa regulation of December 2005 . This means that one can claim a sunscreen is water resistant when it mantains its sun protection factor, at least 50% of it, after controlled immersion in water for 40 minutes.

Novel Claims

Innovative products are beginning to include the claim very water resistant to satisfy the needs of a large group of consumers who are looking for greater adhesion after application. The experimental procedure to support this claim follows the same methodology as the one mentioned above, but increasing the immersion period to 80 minutes.

Through the adaptation of existing methodology, it is possible to evaluate other types of novel claims, such as the capacity of sweat resistant photoprotectors, by simulating sweat- inducing conditions through physical exercise; or sand resistance, a claim that is incorporated in photoprotectors with dry textures which prevent the adhesion of sand to the skin, by limiting the product quantity that comes in contact with it. The objective of these sand resistant photoprotectors is the resistance of the product to the friction produced by the sand on the beach.

Infrared radiation (IR) with a wavelength greater than 750 nm produces a heat effect; lately its role as enhancer of the negative effects of radiation along with UV is being demonstrated. A new perspective as regards protection from IR radiation should be incorporated in the latest developments in innovative photoprotectors, especially from IR-A radiation, which is responsible for the formation of free radicals and the

UVA protection	Critical Wavelength	UVA-PF	UVA-PF	UVA-PF and CW	UVA/ UVB ratio	UVA-PF and CW
Claims	CW >370 nm = Broad Spectrum SPF>15 → decreases risk of skin cancer	PA+ PA++ PA+++	PA+ PA++ PA+++ PA++++ (01.2013)	UVA-PF/SPF ≥ 1/3 / CW >370 nm UVA	UVA ULTRA	UVA-PF/SPF ≥ 1/3 / CW >370 nm
Test Method	CW / FDA final rule 2011	PPD in-vivo ISO 24442	PPD in-vivo ISO 24442	UVA-PF in-vitro ISO24443 (PPD ISO 24442 EU only)	UVA/UVB ratio (incl. Photostability)	UVA-PF in-vitro ISO24443 or PPD ISO 24442
Max. UVA required	>8	>8	>16	>20	>30	>33

Figure 2. Differences labeling on protection against UVA.

reduction of the antioxidant capacity, which particularly exacerbates photo-ageing.

Furthermore, when addressing the issue of photoprotection, the efficacy of the products used after sun exposure (aftersun) should also be assessed. This is a matter of verifying the efficacy of the product: soothing, refreshing and hydrating effect, so that it helps diminish redness caused by UVB radiation. An adequate clinical trial to support this claim involves evaluating the disappearance of erythema (controlled) after application (in the presence of the product under investigation, at different times of the trial.

With reference to tanning boosters, their efficacy is verified when the tanning effect is enhanced. To validate this claim, the subject is submitted to UVA radiation after application of the product under investigation and the increase in pigmentation is evaluated at different times, versus a placebo, using colorimetric techniques.
As for the self-tanning efficacy of a product, this does not require exposure to UV radiation; what needs to be demonstrated is that with continued use of the product tanning is enhanced, which is determined by colorimetric techniques.

Regarding the latest developments in sun product research, it is worth mentioning recent research that opens up a new line of investigation. This research has its origins in the disputed theory which claims that while photoprotectors offer protection, they also reduce the efficacy of the radiation responsible for the generation of vitamin D in the skin. In this field, compounds capable of having a different UV absorption capacity along the spectrum are being investigated .

Key factors for the efficacy of sun products

Three main factors that have a direct or indirect influence on the efficacy of a sunscreen product can be identified.

- 1st Factor: Formulation: the relevance of focusing on photoprotectors capable of protecting skin from the whole spectrum of UV radiation (spectral homeostasis) has been emphasized. At the same time, it is important to highlight the relevance of incorporating antioxidants in the formulation to counter the oxidative effects caused by solar radiation (those of UV radiation, as well as infrared and even the visible range).

- 2nd Factor: Applicability of the photoprotector: In the past, the organoleptic qualities of photoprotectors were not very pleasant for the end user; they tended to be very thick emulsions which left a high percentage of residue on the skin as well as an oily sensation, which made application uncomfortable. Currently, a lot of progress has been made in this area, with the development of photoprotectors with easy extensibility over the skin, which greatly facilitates their application.

- 3rd Factor: Guidelines on the amount of photoprotector to apply: Studies to determine photoprotective efficacy from UVB and UVA are carried out by applying 2mg/cm2 of a sunscreen product on the skin. The average recommended measure is the whole palm of an adult's hand and half the palm of a child's to obtain the right amount of sunscreen. If the amount of sunscreen applied is less than this, the protection factor of the sunscreen will be lower than the one claimed. Recent studies show that the average amount applied is between 1 and 0.5 mg/cm2. Table 1 shows the average SPF in relation to the amount of product applied.
Awareness of the harmful effects of solar radiation on our skin has demonstrated the need for photoprotection. The intrinsic protection offered by our organism (melanin synthesis and thickening of the top layers of the skin) is insufficient, which is why it is vital to resort to exogenous photoprotection. In this regard, the combination of using a suitable sunscreen product, which offers spectral homeostasis and contains antioxidants in its formulation, and applying it properly in the right amount will guarantee adequate protection from the sun.

SPF	2 mg/cm ^{2}	1 mg/cm ^{2}	0,5 mg/cm ^{2}
15	15	3,9	2
30	30	5,5	2,3
50	50	7,1	2,7

Table 1. Real SPF in relation to the quantity of sunscreen applied.

Bibliography

- Fitzpatrick. Dermatología en Medicina General. 7ª Edición.

- Quan T, Quin Z, Xia W, Shao Y, Voorhees JJ, Fisher GJ. Matrix-degrading metalloproteinases in photoaging. J Invesitg Dermatol Symp Proc. 2009 Aug; 14(1):20-24

- ISO 24444:2010. Cosmetics - Sun protection test methods - In vivo determination of the sun protection factor (SPF)

- ISO 24443:2012. Determination of sunscreen UVA photoprotection in vitro

- ISO 24442:2011. Cosmetics -- Sun protection test methods -- In vivo determination of sunscreen UVA protection

- International Sun Protection Conference, Inspirations from Nature, 13 edition, 9-10 June 2015, London. Uli Osterwalder. Basf

- Guidelines for Evaluating Sun Product Water Resistance, 2005.

- Kockott D, Herzorg B, Reichrath J, Keane K, Holick M. New approach to develop optimized sunscreens that enable cutaneous vitamin D formation with minimal erythema risk. PLoS One. 2016 Jan 29;11(1):e0145509. doi: 10.1371/journal.pone.0145509. eCollection 2016

- Adapted of Gilaberte Y, Coscojuela C, Sáenz de Santamaría MC, Gónzalez S. Fotoprotección. Actas Dermosifiliogr 2003; 94(5):271-293