Sun protection: on the efficiency of UV filters

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Whenever the skin is exposed to bright sunlight, the natural protective mechanisms of the skin will no longer be sufficient. Sun protection creams are inevitable in order to protect the skin against the negative effects of UV radiation. How do the UV filters in sun protection creams work and how efficient are they actually?

Nucleic acid (DNA) components helped the first organisms on our earth to protect against the UV radiation of the sun. Besides the melanin of the skin and our hairs they are the most important natural protection against UV radiation. Sun protection creams complement this natural protection.
In terms of total energy, the ultraviolet radiation (UV) in sun light amounts to approximately 5 %. In terms of the energy type, we are dealing here with specifically high energy that can break down chemical bonds of organic substances. As a consequence, decomposition products and free radicals will form which, among others, cause premature skin aging. Due to hereditary protection mechanisms and depending on the individual skin type every person has his **individual time span** during which he is protected against erythema. In other words, this is the span of time untanned skin can be exposed to the sun without developing erythema. It is possible to either estimate this **individual protection** or alternatively calculate it with the help of an artificial light source.

International Standards

Unfortunately this individual protection only takes account of the individual protection factor against UVB radiation. Yet, the UV spectrum of sun light includes further wave length ranges with different effects:

- **UVA radiation (320-400 nm)** amounts to about 90 % of the UV radiation. It penetrates as far as the dermis (cutis), forms radicals and damages the collagen structures of the skin. Hence, it accelerates skin aging. There is only a slight risk of erythema; however, there is a serious risk of specific forms of skin cancer due to DNA damages.
- **UVB radiation (280-320 nm)** amounts to about 10 % of the UV radiation, penetrates as far as the epidermis and is responsible for sun burns (erythema) and the increased risk of skin cancer. On the other hand, UVB also induces the formation of melanin and thus leads to an increased individual protection. Low doses of UVB even have health-promoting effects due to the formation of vitamin D_3 (cholecalciferol).
- **UVC radiation (100-280 nm)** also is contained in sun light but absorbed in the upper atmosphere.

As a matter of fact, sun screen products have to cover both the relevant wave ranges of UVA and UVB. The current recommendation of the EU commission now provides for a UVA protection factor which amounts to at least one third of the UVB protection factor (SPF). This implies a proportional increase of the UVA protection factor along with the UVB factor. By contrast, up to now, the Australian standard has been favored according to which a sufficient UVA protection is provided and can be labeled if the respective product allows penetration of maximal 10 % of the UVA radiation under laboratory conditions. Hence, the Australian standard is independent from the UVB factor labeled. The UVA protection is measured with the in-vivo PPD method (PPD means persistent pigment darkening) or a correlating in-vitro measuring set up by COLIPA (European Cosmetics Association). Products corresponding with the EU recommendation may be labeled with a “UVA sign”.

Fig.: UVA sign

Labeling the **critical wave length** is a quality feature and allows information on the wave spectrum of the UVA filter in the long wave range. The critical wave length informs on the maximum long wave UVA absorption of a 90 % absorption integral of 290 to 400 nm. The EU

commission recommends a critical wave length of at least 370 nm.

How UV filters work

Sun protection filters can work in different ways. **Mineral filters** scatter and reflect the light. This also applies for make up pigments although they only provide a low sun protection factor. Mineral filters like zinc oxide and titanium dioxide stay on the skin surface. They are adequate filters for small children and diseased (permeable) skin. In the past few years, mineral filters in nanoparticular form that mainly absorb the UV light and transform it into thermal energy like chemical filters have become widely accepted. While mineral nanoparticles do not penetrate into the skin, **chemical filters** consisting of organic substances show considerable penetration rates depending on their respective structure, a fact which may lead to irritations or allergic side effects. That is the reason why mineral filters are recommended for small children.
An interesting issue is the actual efficacy of the different filters: If a filter molecule absorbs the energy of UV light in form of photons it will move into an excited state. This excited state should only be transitory, otherwise there is a high probability of free radicals being formed instead of thermal energy. While the natural filters melanin and DNA transform the radiation into thermal energy with about 100 percent quantum efficiency, chemical filters are far less effective. The quantum efficiency of octyl methoxy cinnamate (4-methoxy cinnamic acid 2-ethylhexyl ester) still is around 80 % while others sometimes amount to less than 50 %. If worst comes to worst, radicals will form which then have to be disarmed with the help of additional antioxidants. Benzophenons may even cause photosensitizations. In this context it has to be mentioned that proteins and the resulting amino acids of the NMF are the most important natural radical scavengers. Hence, a preserved NMF has superior priority also for sun protection purposes.

Sun protection also has limits

The SPF increases along with the concentration of UVB filters in sun protection creams. Multiplied with the individual protection it states the maximal sun exposure before developing erythema: **individual protection time span x SPF = maximum sun exposure.**

A problem with the development of sun protection creams is the exact definition of the SPF:

$$SPF = \frac{\text{Minimal erythema dose (MED) of the protected skin}}{\text{Minimal erythema dose (MED) of the unprotected skin}}$$

As we are dealing here with radiation doses that are applied over individual time spans the SPF of a product can only be measured experimentally with the help of voluntary test persons. This implies that the development of sun screen products becomes rather expensive since the concentrations of the filters needed for a defined SPF cannot be accurately calculated in advance.
A product with SPF 30 allows double the exposure to radiation than a SPF 15 product. The protection provided by a SPF 15 product already amounts to 93.3 % and only increases by 3.4 points up to 96.7 % for a SPF 30 product. The percentage stated is always based on the effective radiation doses but not on their absorption or transmission. It clearly shows that high sun protection factors can only be achieved with disproportional high quantities of chemical additives. There is no 100 % protection and that is the reason why the term “sun blocker” is rejected by EU authorities. Realizing a high SPF with mineral filters or natural cosmetic products practically is impossible. That is why a high SPF should only be applied if it is inevitable. Adequate head covering and appropriate clothing are the better solution on a long term base. The EU commission classifies sun screen products as follows:

Sun protection factor (SPF)	Protection in [%]	Product category
6	83.3	base
10	90	base
15	93.3	medium
20	95	medium
25	96	Medium
30	96.7	high
50	98	high
50+		very high

The individual protection time span mentioned above unfortunately is inconsistent. It rather depends on the daytime and the season, the geographic location as well as on the altitude above sea level. Hence, the risk of erythema is specifically high at noon, in summer time, near the equator and on high mountains. It should be added that there are also local factors like pure air (polluted air absorbs UV light) and the additional exposure due to reflections at the coast (water and sand) and in the mountains (snow reflects up to 85 % of the radiation). Also diffuse light (lightly cloudy sky, light fog)

may be treacherous as the scattered radiation then comes from all sides.
Some guidance is provided with the **UV index (UVI)** published via internet by the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz), Germany, which, dependent on the respective season, informs on the radiation in different locations all around the world. The UVI is measured and calculated with the help of a complicated formula. In Germany, it is around 0 in winter, in summer around 8 at a maximum, whereas it amounts to 13 at the equator at noon with the highest position of the sun (as e.g. Singapore, at sea level).
A rule of thumb says that the SPF should at least be twice as high as the UVI value and for small children it should even be four times the UVI number. As a matter of fact, the latter mentioned recommendation can be considered as nonsense since small children should never be exposed to direct radiation. By analogy, this also applies for the Celtic skin type in our climes with an individual protection of 5 to 10 minutes (in comparison to the Mediterranean skin type with 30 to 40 minutes). The individual protection of course prolongs with increasing melanin formation. The old rule saying that sun exposure should be started in low doses and then slowly be prolonged still is applicable, though.

Dosage and side effects

In order to achieve the respective sun protection factor, it is vital to apply a sufficient amount of the product on the skin; according to the COLIPA recommendation this would be **2 mg/cm^2** of skin. In other words: To protect the whole body of an average adult about 6 teaspoons of the product are required which is equivalent to about 36 grams.
Water resistance is not defined though. There are indeed some recommendations, however, with respect to the application of the products these recommendations are easily put in perspective. It is advisable to take a close look at the INCI and the penetration properties of the product. A hydrophobical formulation including lipid substances, W/O emulsions and the combination with oleogels (lipogels) is an excellent precondition in this context. It is also vital to reapply the product after long stays in water or sport activities.
Regarding the formulation of sun screen products, the above mentioned **chemical stability** of the filters towards radiation is a significant issue. In this context, the combination with additives like emulsifiers, preservatives and perfumes is important. These substances may cause instabilities and undesired dermatological side effects due to both the formation of peroxides and also photosensitization. For some time, there have been speculations based on animal tests about **side effects** in form of estrogen-like systemic effects caused by cinnamic acid esters, however in practice, these effects could not be proved. The natural urocanic acid of the body which can be found in sweat particles, among others, and which absorbs UVA radiation is banned from sun screen products due to the fact that the absorption of radiation energy causes the transformation from trans- into cis-urocanic acid that has immunosuppressive effects.

Precautions

Although sun screen products are able to protect against skin cancer and UV-related premature aging of the skin, they cannot prevent **infrared radiation (IR).** IR light which is synonymous with thermal radiation leads to high thermal stress of the skin. In this connection, the superficial proteins in the skin are damaged and will denature. The skin is immensely stressed and will age prematurely even without UV influence. Today, the EU commission demands for appropriate precautions labeled on the products as follows: “Since thermal radiation of the sun (infrared) is rather stressful for the skin, do not stay too long in the sun even while using a sun screen product. Over-exposure to the sun is a serious health risk. Keep babies and small children out of direct sun light."

Effective accompanying substances...

Besides the traditional filters there are interesting product solutions aiming at the side effects of sun light. They inhibit the collagen and elastin degradation or stimulate their regeneration. **Nanoparticular frankincense resin** e.g. inhibits the collagen-degrading metalloproteinases. It can even be successfully used for the care of the skin suffering from sun-related actinic keratosis. **Liposomal vitamin C derivatives** support the collagen regeneration and react with free radicals. Products containing the **polysaccharide CM-glucan** protect the DNA and slow down erythema formation. In connection with mineral filters, it should also be mentioned that colorless nanoparticular titanium dioxide is better tolerated than the larger white particles. Formulated in a cream matrix these tiny particles are definitely harmless.

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