Innovative method to evaluate sun damage and future sunscreen products more efficient, more safe and more eco-friendly.

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Abstract

Introduction

Global climate changes, pollution and the increasing scientific knowledge are contributing to making sunscreen essential in our life to prevent sun damages and aggressive skin alterations. Develop innovative and effective sunscreens is a challenging task in the research and development field. Sunscreens must protect against skin damages, while being safe, sensory pleasant without causing environmental alterations. Organic UV filters, while proposing great cosmetic advantages, present the risk to penetrate the skin (1) ; can be photo-unstable, and their release in the aquatic environment has a significant impact on the marine environment especially on the coral.

Methods

Current sunscreen products based on organic UV filters do not remain effective for long and must be re-applied every two hours: lack of efficacy. Moreover, they can penetrate the skin inducing safety issues. FTIR spectroscopy provides direct information concerning the lipid organization inside the stratum corneum which supports the skin barrier function. Vibrational Spectroscopy (FTIR and Raman) was used to investigate and compare different technologies used to develop sunscreens products in terms of efficacy and safety. Recently, *In vivo* spectroscopy analysis was also done to generate 3D face mapping showing the UV filters distribution on the face overtime.

Results

FTIR analysis has shown that sunlight exposure significantly altered this lipid organization with a direct impact on the skin barrier function which dramatically increases the skin's permeability regarding organic UV filters. FTIR and Raman imaging has shown micro-encapsulation technology, or the use of film formers improved the retention of organic UV filters on the skin surface, increasing the sunscreen efficacy and prevented the penetration of these UV filters inside human skin limiting their toxicological risks. These technologies provided new directions to develop safer and more efficient sunscreen products. These results were validated during pre-clinical trials with 3D face mapping showing the distribution of UV filters over time. This new approach opens an innovative communication of these products for the final consumer.

Discussion and Conclusion

While no regulations are yet established, it is becoming obvious that organic UV filters penetration should be taken into consideration in the development of future sunscreen products especially with the global warming that we are suffering. 3D face mapping showing the distribution of UV filters over time is an innovative communication approach for the consumer highlighted the benefits of innovative technologies (encapsulation, film former) in the sun protection field. The technologies investigated in this study allowed to increase the retention of UV filters, increasing their effectiveness and drastically reduce their toxicity. Safer and more efficient sunscreen are within reach.

Keywords: Skin barrier, FTIR and Raman spectroscopy, UV filter penetration, long-acting sun protection, 3D mapping

Introduction

Global climate changes, pollution and the increasing scientific knowledge are contributing to making sunscreen essential in our life to prevent sun damages and more aggressive skin alterations like sun burn and in the worst-case skin cancer (Krutmann et al., 2021).

The development of innovative and effective sunscreens is a challenging task in the research and development (R&D) field as sunscreens must protect the skin from the UV radiation, while being safe, sensory pleasant and without causing environmental alterations (Paul, 2019).

The use of organic UV filters is very common and, while proposing great cosmetic advantages, present the risk to penetrate the skin; be photo-unstable, and their release in the aquatic environment has a significant impact on the marine environment especially on the coral (Schneider & Lim, 2019; Shetty et al., 2023; Vuckovic et al., n.d.; Yeager & Lim, 2019) .

Within this frame of reference, there are several alternatives that can improve the sunscreen photoprotection with a better skin retention, more uniform distribution and reduce the risk of penetration through the skin. Indeed, the use of specific ingredients in the formulation, as film former polymers is one interesting alternative, that can improve the sunscreen performance (Deng et al., 2015; Suh et al., 2019; Tan et al., 2021). The use of encapsulated UV filter is another alternative that can reduce the risk of toxicity associated with organic sunscreens as it can reduce the risk of penetration and also can improve the UV filters distribution on the stratum corneum and stability (Cozzi et al., 2018).

Current organic UV filters do not remain effective for long and the recommendation is to be re-applied every two hours meaning their efficacy can be improved. Moreover, there is the risk of penetrating the skin beyond the stratum corneum region, thus presenting lack of safety (Prado et al., 2017; Souza & Maia Campos, 2017).

In this context, the aim of the present study was to evaluate three different sunscreens, octocrylene and avobenzone in their free form, encapsulated or associated with film formers using vibrational spectroscopy to evaluate the penetration profile and the skin distribution *in vivo* and *ex vivo*.

Materials and Methods

Sunscreen Formulations

The sunscreen formulations used in this study were developed based on the following ingredients: cetearyl alcohol, glyceryl stearate, C12-15 Alkyl Benzoate, Bis-PEG/PPG-20/5 PEG/PPG-20/5 Dimethicone (and) Methoxy PEG/PPG-25/4 Dimethicone (and) Caprylic/Capric Triglyceride, Caprylic/Capric Triglyceride, BHT, Propylene glycol, EDTA and Water.

The organic UV filters used were avobenzone at 3% concentration and octocrylene 10% concentration in a free form or encapsulated. For the third formulation, a film former was incorporated in the formulations with the free form UV filter, the film former ingredient was the Polyamide-3.

Confocal Raman measurements

For this study, 2x2 cm *ex vivo* human skin samples obtained from plastic surgery were analyzed for each treatment. For each skin sample a series of 6 Confocal Raman spectroscopic lines were scanned into the skin sample at 1-micron steps for 25 microns deep. Confocal Raman images were acquired using a WITec Alpha-3000R plus confocal Raman microscope (UIm, Germany) equipped with a 532nm laser

The Spectral parameters used to scan the skin samples were:

Laser frequency: 532 nm

Laser power: 5 mW

Acquisition time: 2 exposures at 6 seconds/spectrum

Spectral range: 3500– 400 cm^{-1}

FTIR *in vivo* measurements

In vivo spectroscopic measurements were conducted, and the data were used to generate 3D face mapping showing the UV filters distribution on the face overtime.

The skin was evaluated by means of FTIR spectroscopy *in vivo* measurements using a REMSPEC® system, to evaluate the presence of the sunscreens under study. For this purpose, 15 measurements were conducted on the panelist's face region.

The ATR-FTIR spectra was recorded in the mid-IR region range from 4000 to 950 cm^{-1} with a spectral resolution of 8 cm^{-1} and 128 scans accumulation.

Spectroscopy analysis

The hyperspectral images were analyzed using Isys Chemical Imaging analysis 5.0 software (Malvern Instruments Limited, Malvern Works, UK).

For the confocal Raman measurements of the octocrylene it was calculated the peak height of 1590 cm^{-1} normalized to 1646 cm^{-1}. For the avobenzone it was the peak height of (***) normalized to 1646 cm^{-1}.

For the in vivo spectroscopy study, the band area of the octocrylene (1745 cm^{-1}) or avobenzone (1531 cm^{-1}) was calculated after normalization to the amide I (1655 cm-1) band. For statistical analysis the pixel values were extracted from the hyperspectral images and ANOVA test was applied using GraphPad Prism 8 software (San Diego, California, United States).

Results

Confocal Raman measurements

The ex vivo study comparing the 3 different formulations showed that the free form of sunscreen presented skin penetration at 25µm depth, which means the free sunscreen presented penetration bellow the stratum corneum region. It is also possible to observe that the free form doesn't present a smooth distribution on the skin when compared to the formulation with the addition of the film former ingredient. The film former reduced the penetration and also improved the spreadability and uniformity of the sunscreen on the skin. The encapsulation of the sunscreen promoted a great retention on the stratum corneum region, presenting a uniform profile and also a more intense presence when compared to the free form, which is related to degradation of the sunscreen overtime.

FTIR *in vivo* measurements

The results of the in vivo study showed that the free sunscreens presented stronger presence in some areas, showing the uneven distribution. The sunscreen with film former presented a more uniform distribution on the face while, the encapsulated sunscreen presented a more uniform as well as a higher concentration of UV filters on the face. The UV filters presence was also investigated overtime. With the free sunscreen we can observe a reduction in the UV filters presence after 1 hour of application, while with the encapsulated sunscreen the UV filters present a great retention on the skin until the 2-hour timepoint.

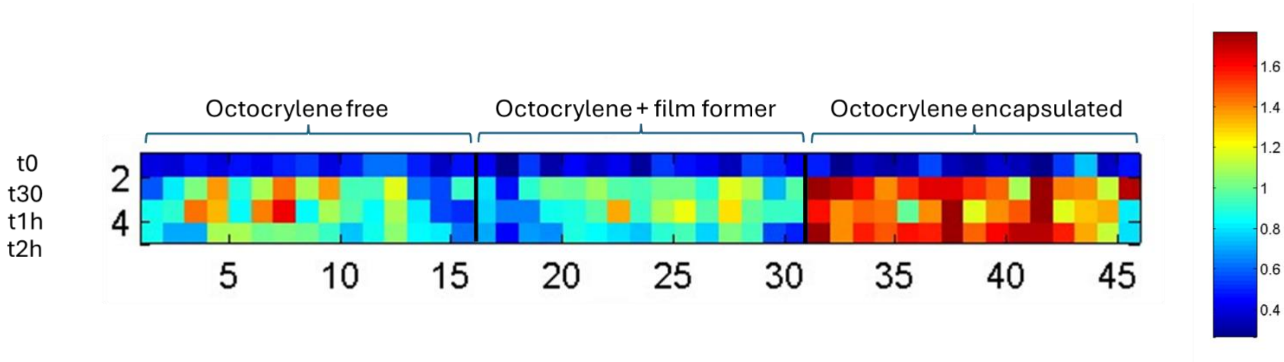

Figure 1: Hyperspectral in vivo FTIR images for the octocrylene content in in-vivo skin after application of the sunscreen containing octocrylene free, sunscreen with octocrylene + free former and sunscreen with octocrylene encapsulate. The image intensity results from the peak area of the octocrylene (1745 cm^{-1}) normalized to the amide I (1655 cm^{-1}) band. The relative octocrylene content can be evaluated by the accompanying color bar where red indicates higher content and blue the lowest.

Discussion

Sunscreen regulations are still a topic of discussion, and some are yet to be established. UV filter penetration should be taken into consideration in the development of sunscreen products especially with the global warming that we are suffering. In the present study it was possible to observe a good correlation between the results obtained in both ex vivo and in vivo studies.

In both studies it was possible to observe an improvement in the sunscreen distribution with the association with the film former. The encapsulated sunscreens presented a more uniform distribution as well and a stronger retention of organic UV filters on the skin surface.

In the literature there is evidence that support the safety concern associated with sunscreens penetration (Prado et al., 2017; Souza & Maia Campos, 2017). In our study it was observed Octocrylene penetration below the stratum corneum region, meanwhile the two different technologies studies (encapsulation and film former) provided an improvement in the safety profile, which show the benefits of these type of technologies for the research and development of new formulas(Deng et al., 2015; Suh et al., 2019; Tan et al., 2021).

The findings observed by Confocal Raman study were also supported by in vivo study using *in vivo* FTIR, which showed an improvement in the distribution profile of the UV particles along the *stratum corneum* region. The free form presented agglomerates in the skin, which is not desirable, as the better distribution, better the protection observed (Adlhart & Baschong, 2011; Keshavarzi et al., 2022). The film forming technique is aimed to improve the uniformity of the formulation as well as the retention of the sunscreen on the skin, which was only partially true. The obtained results showed an improvement in the distribution, but no improvement in the retention, meanwhile the encapsulation promoted an improvement in both factors. Previous studies from our research group also showed that encapsulation can lead to sunscreens less susceptible to degradation, which is also another advantage of this technology (Cozzi et al., 2018).

The in vivo study, along with the depth profile observation of those formulations promoted a comprehensive view of the sunscreen interaction with the skin and how the application of different ingredient technologies can support the development of safer cosmetic products with an improved performance.

Conclusion

This innovative communication approach for the consumer highlighted the benefits of innovative technologies (encapsulation, film former) in the sun protection field. The technologies presented in this study allowed to increase the retention of UV filters, increasing their effectiveness and drastically reduce their toxicity. Safer and more efficient sunscreen are within reach.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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