Identifying the Biomechanical Effects of UV Resistant Molecules and Nanoparticles on Human Skin

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Abstract:

The stratum corneum (SC) is the outermost layer of the epidermis and experiences significant amounts of mechanical stress. A lipid matrix surrounding layers of protein-filled cells forms the stratified SC, which is essential for proper functioning at the nano- and micron-scale. Ultraviolet (UV) radiation due to sun exposure can alter the organization and structural integrity of the SC components. The administration of UV-absorbing chemical compounds and nanoparticles, namely titanium dioxide (TiO_2) and zinc oxide (ZnO), can reduce damage. However, it is not fully understood how these UV-resistant treatments interact with the SC, and their efficacy at protecting biomechanical properties from UV exposure is unclear. In this work, we investigated the ability of various topical sunscreens containing UV-resistant molecules and nanoparticles to protect the biomechanical properties of UV-irradiated human SC. We examined the tissue's resistance to crack propagation, given by the intercellular delamination energy. We also used attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) to study UV inhibitor diffusion into the SC as well as structural changes that occurred from UV exposure. We found that the UV-resistant treatments successfully protected the biomechanical properties up to relatively large UV dosages.

Introduction:

The stratum corneum is essential for wound healing, infection prevention and equally important, protecting underlying layers of skin from solar radiation. UVB radiation in particular has proven harmful to the skin, not only on a cellular level but also on a biomechanical level. Irradiation damage can produce changes in the lipid matrix and cellular structure, leading to disrupted barrier function. This obstructs the skin's ability to desquamate, or shed, as well as provide mechanical strength. The effects of this include cracking and chapping, as well as other cosmetic defects [1].

Nanoparticles such as TiO_2 and ZnO possess UV-inhibiting qualities, making them ideal components of commercial sunscreens. However, it is unknown how they interact with and protect the stratum corneum from harmful radiation.

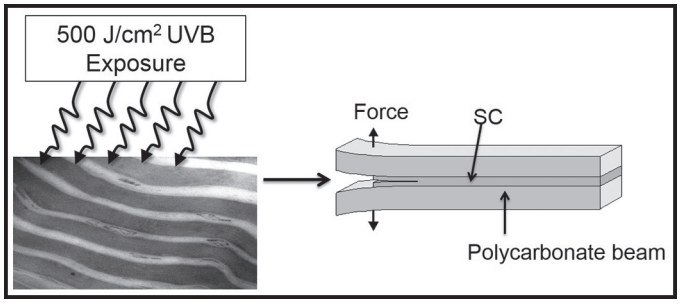

Figure 1: Double cantilever beam testing of stratum corneum exposed to UVB radiation with or without nanoparticle sunscreen treatment yields the extent of cellular cohesion.

Experimental Procedure:

We obtained samples of SC through blunt dissection of human cadaveric tissue from Caucasian female donors. To analyze the mechanical properties of the SC, double cantilever beam (DCB) testing was employed to yield the delamination energy, G_c (J/m^2), which reflects the extent of cellular cohesion within the SC. Figure 1 displays the DCB sample configuration. Nanoparticle sunscreen (SS) was applied to SC samples to obtain an even coating of 2 mg/cm^2 before exposure to 500 J/cm^2 of broadband UVB radiation.

Fractured samples were repeatedly delaminated by attaching a new polycarbonate beam to remove lower layers of cells from the original beam with adhered SC. This yielded second and third delamination energies, which increased with depth due to greater intercellular cohesion in the SC.

We used attenuated total reflectance Fourier transform infrared spectroscopy to characterize fractured samples. Changes in height and location of characteristic C-H lipid peaks further revealed how nanoparticle sunscreen interacted with the SC.

Results and Conclusions:

We employed dynamic light scattering particle sizing to obtain an estimate of the nanoparticle diameter. An average diameter of

135 nm was seen, which was larger than expected. This discrepancy was likely due to agglomerations caused by the sunscreen ingredients.

We obtained the delamination energies of samples with no treatment, 500 J/cm^2 UVB only, sunscreen only, and sunscreen plus 500 J/cm^2 UVB. As seen in Figure 2, samples irradiated without nanoparticle sunscreen have significantly lower delamination energies due to reduced intercellular strength. However, the sunscreen-treated and UVB-irradiated samples possess delamination energies that are not significantly different than that of the unexposed samples. This indicates that the sunscreen is indeed protecting the SC from UV damage.

Figure 3 shows that underlying layers of the SC are protected in the same fashion, as the second and third energies of sunscreen-treated samples were greater than the untreated plus irradiated samples.

ATR-FTIR analysis showed peak shifts, which suggest changes in SC lipid fluidity due to emollient diffusion into lower layers [2]. The lack of ZnO and TiO_2 peaks near 2275/2350 cm^{-1} and 1645/3400 cm^{-1}, respectively, (not shown) suggest there was no nanoparticle diffusion.

Overall, it was determined that nanoparticle sunscreen effectively protects the biomechanical properties of the stratum corneum at relatively high broadband UVB dosages. Diffusion of the emollient was suggested by peak shifts of the second and third delamination lipid C-H stretches. However, nanoparticle diffusion was not observed, in agreement with the unexpectedly large particle size. This is fortunate, as unwanted nanoparticle diffusion is a potential harm of using such sunscreens.

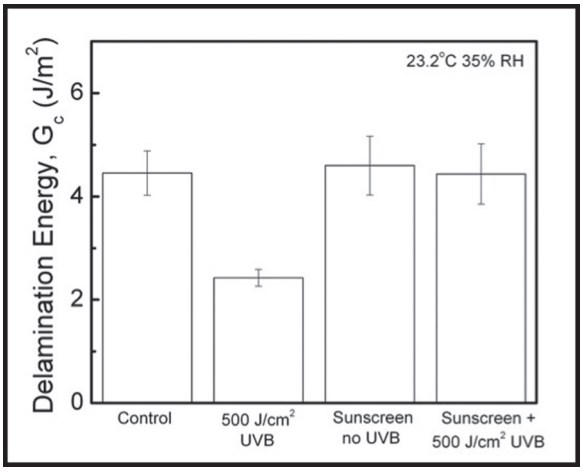

Figure 2: SC delamination energy gives crack length and first delamination energies of various samples.

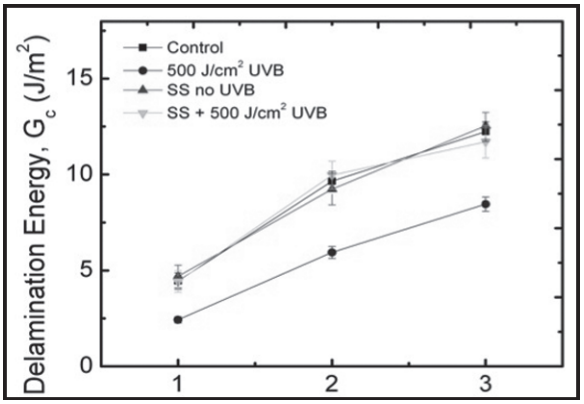

Figure 3: Delamination energy as a function of depth into the stratum corneum.

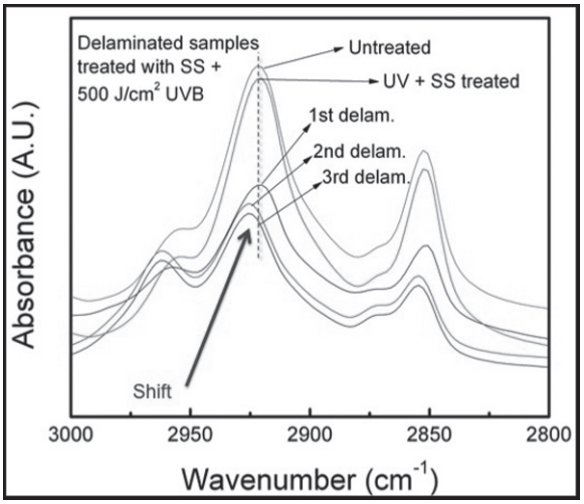

Figure 4: Overlapped ATR-FTIR spectrum shows changes in the characteristic asymmetric and symmetric C-H lipid stretching.

Future Work:

We hope to further this study by exploring how nanoparticle sunscreen can affect previously UV-damaged tissue, wherein the barrier function has already been significantly compromised. ATR-FTIR analysis of sunscreen-treated damaged tissue will also help us understand the way nanoparticles diffuse into lower layers of the SC.

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References:

[1] Biniek K., et al. Solar UV radiation reduces the barrier function of human skin. Proc. Natl. Acad. Sci. U. S. A. 2012, 109:17111-171162.

[2] Levi, K., et al. Emollient molecule effects on the drying stresses in human stratum corneum. Br. J. Dermatol. 2010, 163:695-703.