

# Fluorescent silica colloids for study and visualization of skin care products

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**Background:** The efficacy of skin care products depends on the time and dynamics of their absorbance by the skin, and its spatial distribution on the skin. Regular scrape-based methods may depend on the operator and are destructive and invasive in nature. Here, we describe a novel method based on non-contact optical measurements to trace the location and dynamics of skin care products on the skin.

**Methods:** We use fluorescent silica colloidal particles of micron sizes at a rather small concentration as non-invasive tracers. As an example of skin care products, we use two base materials: either glycerin or vaseline. A mixture of each product with fluorescent particles is applied on human skin. The amount of fluorescence is monitored by means of a fluorescent spectrometer. The scraping method is used to compare with the spectroscopic measurements.

**Results:** Fluorescent tracers make the skin care product visible under UV light. This allows obtaining an optical image of the spatial distribution of the product on the skin. The quantitative data of fluorescence are well correlated with the scrape data. Comparison of the difference in the spectral and scraped mass data reveals the details of accumulation of the skin products in skin cracks and crevices.

**Conclusion:** We described an efficient non-invasive benign method to quantify dynamics and to perform mapping of emollients and humectants on the skin.

**Key words:** skin care products – fluorescence – colloids – spectroscopy

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HUMAN SKIN is the body's first wall of defense against the outside environment. It protects the body from dehydration, bleeding and invasion of microorganisms, and plays the role of a 'thermos' to maintain body temperature (1). The skin has three major layers: the epidermis, the dermis and the subcutaneous fat layer. The stratum corneum (part of the skin that forms the junction of the body with the external environment) has been widely investigated by the cosmetic industries for skin care (2, 3). For example, the role of the stratum corneum in regulating the transepidermal water loss has been investigated (4). It has been reported that under a normal condition, up to 15% of the stratum corneum consists of water (5). The natural functions of skin do not work very well if the water content declines below 10% (6). The protective oil produced by the sebaceous glands, together with the stratum corneum, plays a very vital role in determining the health and nature of the human skin. Long exposure to water and excessive use of soap are, among others, the most

important reasons quoted for the removal of the protective oil layer from the skin. This results in 'dry' skin problems, often experienced also during winter due to long exposures to cold and dry air (7).

Different skin care products are used to hydrate dry skin. The two major kinds of moisturizers available in the market are emollients (such as petroleum jelly, mineral oil and lanolin) and humectants (such as glycerin, sorbitol, lactic acid and urea) (8). While petroleum jelly provides the best barrier properties and is comparatively cheap, it also has several disadvantages. It is greasy and harder to wash off. While attempting to hold moisture in the skin, it traps the toxins and wastes that are inside the skin's layers. This, for example, may result in premature aging of the skin. Glycerin, on the other hand, attracts and holds water on the skin's surface. But while doing so, it will draw moisture from the lower layers of the skin and hold it on the surface. This means that glycerin will dry the skin from inside out. Moreover, there is evidence that glycerin is a

human mutagen (9). Although these products have been in use for a long time, the pharmaceutical companies have often found it difficult to validate quantitatively the life span of their activity on the skin.

In the present work, we introduce a novel technique to trace and study the presence of skin care products on skin using fluorescent silica particles (10, 11). To demonstrate the method, we use two base materials: glycerin and vaseline as skin care products. Fluorescent particles are physically mixed with the products. The method is comparatively benign due to encapsulation of the fluorescent dye within the silica particles and does not use any complementary modification of the silica surface for tagging. The method does not require sophisticated instruments. It can be used both under ambient conditions and in liquids directly.

## Materials and Methods

### *Fluorescent silica colloids*

Synthesis of fluorescent silica colloids is described in detail elsewhere (11). Briefly, we used cetyltrimethylammonium chloride (CTACl, 25 wt% aqueous solution) and tetraethylorthosilicate (TEOS, 99.999%) obtained from Sigma-Aldrich (St. Louis, MO, USA). Hydrochloric acid (HCl 37.6 wt% aqueous solution) was supplied by Fisher-Scientific (Pittsburgh, PA, USA). Formamide (HCONH<sub>2</sub>, 100%) and dimethylformamide (HCON(CH<sub>3</sub>)<sub>2</sub>, 100%) were produced by J. T. Baker (Phillipsburg, NJ, USA). Rhodamine family laser dyes (R640 and LD700) were purchased from Exciton (Dayton, OH, USA). Solutions were diluted with distilled water (Corning AG-1b, 1 MΩ cm distiller; Corning, Rochester, NY, USA). All chemicals were used as received.

The molar composition of the reactants was 100 H<sub>2</sub>O:7.8 HCl:9.8 formamide:0.11 CTACl:0.13 TEOS. An aqueous solution of concentrated laser dye was added to create a target dye concentration of 10<sup>-3</sup> M in the synthesizing bath. For this work, we used a 50–50 mix of rhodamine 640 and LD700 lasing dyes. After an initial 15 min of mixing, the resulting solution was maintained kept under quiescent conditions for 3 days at room temperature. The particles were collected either by centrifugation or filtering. An image of the synthesized particles is shown in Fig. 1. One can observe a mix of some amount of fiber-like

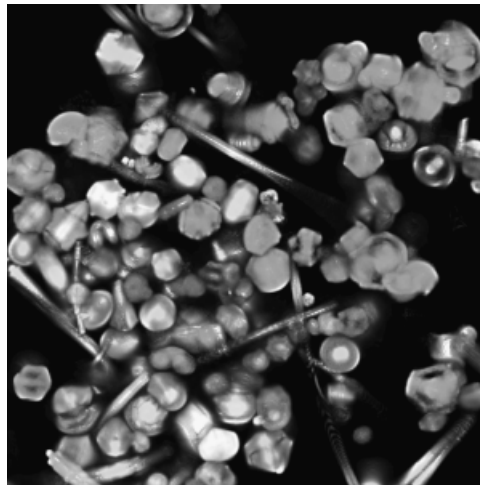


Fig. 1. A  $60 \times 60 \mu\text{m}^2$  optical image of fluorescent silica particles. The majority of the particles are around ‘discoids’, while there are a few fibers.

particles with a large amount of ‘discoids’ with a typical size of ca. 5  $\mu\text{m}$ .

### *Preparation of the mix of vaseline and glycerin with the fluorescent silica colloids*

Glycerin, Natural 99.5% USP (Humco Holding Group Inc., Texarkana, TX, USA) and vaseline (100% pure petroleum jelly, Vaseline Intensive Care, Kingston-upon-Thames, UK) were used as received. Physical mixtures of fluorescent silica particles with vaseline and glycerin were prepared. The concentrations of the particles in the mixtures were maintained at approximately 0.2 wt%. Prepared mixes were stored and used for many days (months if needed) without noticeable deterioration or possible dye leakage.

### *Measurements set-up*

The experimental set-up for spectral analysis is illustrated in Fig. 2. The set-up was placed under a dark chamber to minimize interaction with the external light while recording data. A UV flash light was used as a light source to induce fluorescence. An optical filter (Omega 488 broadband, Omega Optical, Brattleboro, VT, USA) was used to screen the UV light from the source and allowed the only fluorescent signal from the particles to reach the spectrometer. A USB2000 UV-VIS spectrometer (Ocean Optics, Dunedin, FL, USA) was used to detect the amount of fluorescent light. To perform absolute irradiation measurements of the amount of fluorescent material, the spectrometer was calibrated by an LS-1-CAL Calibrated Tungsten Halogen Light Source (Ocean Optics). After this calibration, we

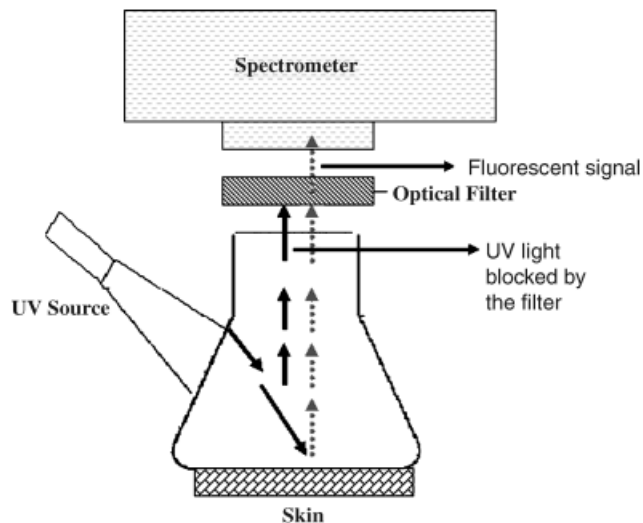


Fig. 2. Schematic representation of the spectrofluorometric setup assembled for the experiments described in the present work.

can assume the amount of fluorescent material on the surface to be proportional to the area under the spectral curve. The area of skin exposed to the skin care products was imaged using consumer digital cameras (Minolta DX1 [Minolta, Mahwah, NJ, USA] and Olympus 3030 [Olympus, Melville, NY, USA]).

The area of the hand under study was cleaned with soap before the application of the mixture to remove contaminants. Spectrometric and weight data were obtained at intervals of 0, 20, 40, 60, 80, 120, 180, 240, 300 and 360 min after application. The amount of glycerin and vaseline left on the skin was measured by gently scraping them out from the skin once with a piece of a 0.5 mm thick aluminum foil. This was done at different intervals of time passed since product application.

## Results and Discussion

Fluorescence from the dye-encapsulated silica particles is very strong and stable. A very small concentration of these particles is sufficient to obtain a strong signal. Indeed, it can be noticed that the drop of glycerin mixture appears as a bright area under UV light but cannot be differentiated from the glycerin drop under regular white light, Fig. 3. The typical size of the fluorescent particles is in the range of 5–20  $\mu\text{m}$ , Fig. 1. This prevents the articles from penetrating into the skin. Finally, silica is a rather chemically inert material. It is believed that the silica particles of such size at these small concentrations will act as a non-invasive tracer with no interference with the skin care products.

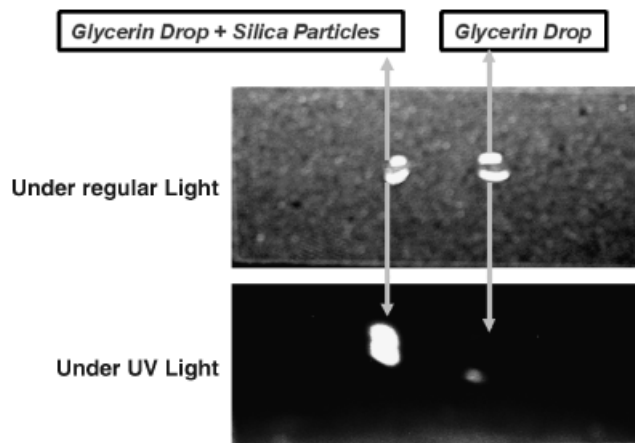


Fig. 3. Image of a drop of glycerin with and without fluorescent particles under normal light and UV light.

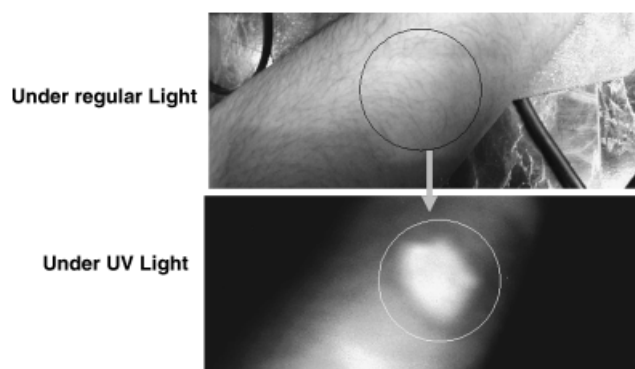


Fig. 4. Image of a forearm showing the area of application of glycerin mixed with the fluorescent particles. The area appears invisible under normal light while it can be clearly seen as a bright patch under UV light.

After applying a small amount of the vaseline and glycerin mixed with the fluorescent particles, the area was imaged by taking images with a digital camera. Figure 4 shows such images when the glycerin mix was applied onto a hand skin surface. While under regular light it was virtually impossible to see the area with glycerin (top image), it was clearly seen under UV light (bottom image). The somewhat washy bottom image is due to low light conditions while the camera was kept just by hands. Potentially, it is not difficult to obtain high-resolution images of the spatial distribution of the skin care products on the skin. Thus the strong fluorescence from the silica particles provided an effective method to monitor visually the distribution of skin care products on the skin surface.

The brightness of fluorescence can be correlated with the amount of product on the skin. We show now that fluorescence can be used for studying the dynamics of adsorption/removal

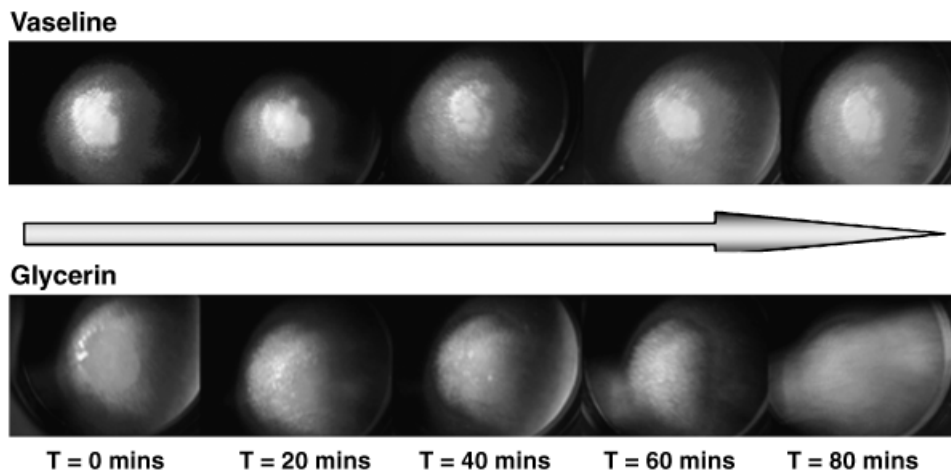


Fig. 5. Series of consequent images of the area of application of glycerin/vaseline mix with the particles taken under UV light.  $T$  represents the time after the initial application in minutes.

of the skin care products on the skin. Because the mix of either vaseline or glycerin with the particles is rather homogeneous, it is plausible to assume that the amount of fluorescent light is proportional to the amount of vaseline/glycerin. After applying vaseline or glycerin, the area of the skin under study was studied further. It was done under the UV light source for various time intervals to detect any visual change first. This experiment was performed to give an approximate time frame of study for the spectroscopic analysis. Visual analysis of the images, Fig. 5, revealed that the decay in the fluorescence signal from the glycerin-covered area was pronounced in the initial 80 min of the experiment. The decay in the vaseline-covered area was at a significantly slower rate when compared with glycerin.

Spectral analysis for both vaseline and glycerin indicated a decay in the fluorescence signal with time, Fig. 6 (the distribution of the relative intensity is shown). Analysis of the area under the curves, shown in Fig. 7, revealed that indeed the decay in the signal was rapid in the case of glycerin, while the decay was slower for vaseline. It can be noted that the initial slope (within 80 min of application) was much higher for glycerin when compared with vaseline. This substantiated the earlier claim after visual analysis that the loss in the activity of glycerin on skin was pronounced and rapid in the initial 80 min of application.

To correlate these measurements with the actual amount of vaseline or glycerin on the skin surface, a control experiment was performed by scraping vaseline and glycerin from the skin

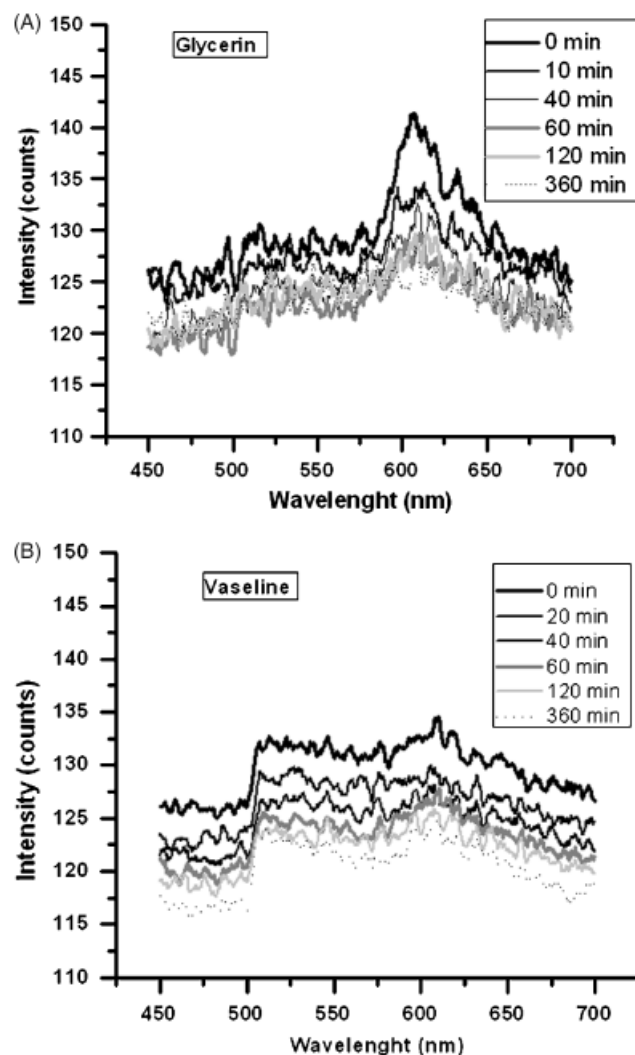


Fig. 6. Spectrographs of the fluorescent signal from glycerin (a) and vaseline (b) mixed with the particles taken at different time intervals after application.

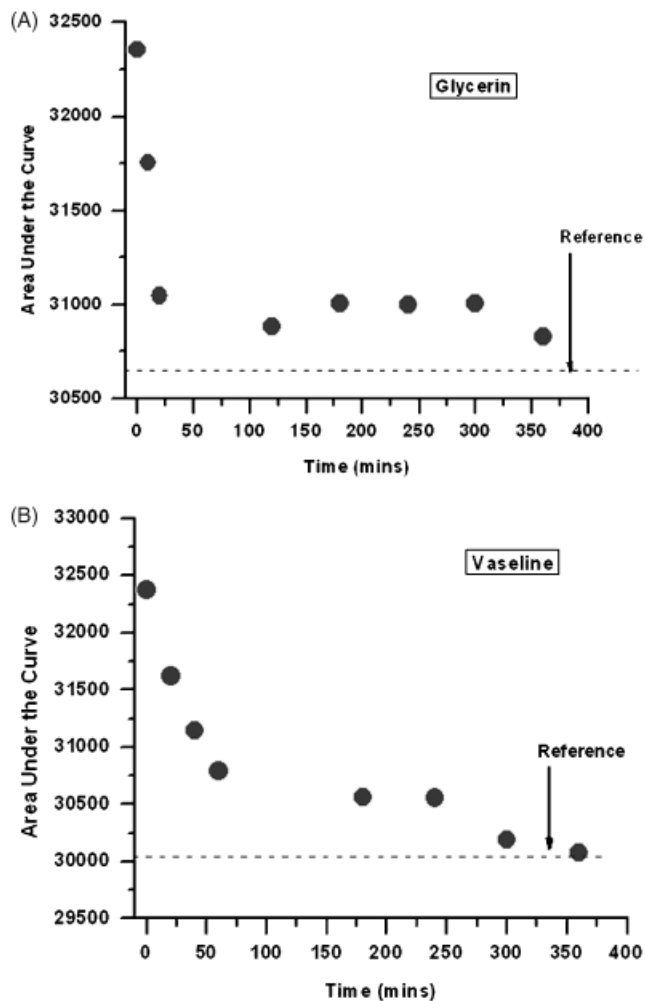


Fig. 7. Area under the spectral curves of shown in Fig. 6 for glycerin (a) and vaseline (b) plotted vs. time.

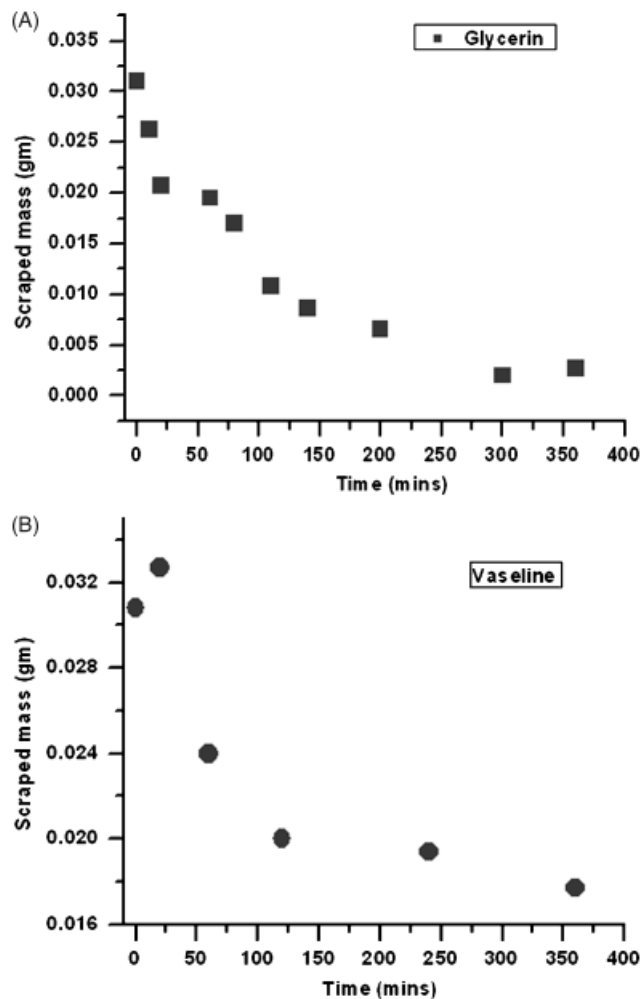


Fig. 8. Mass of glycerin (a) and vaseline (b) scraped from the skin surface plotted vs. time.

surface after different time intervals. Figures 8a and b show the results of measurements of the mass of the scraped material. One can observe a good correlation with spectroscopic measurements, Figs 7a and b. Comparing these two methods of measures, one has to keep in mind that the scraping method is very much operator dependent (for example, it is too hard to control the load force while scraping). Consequently, it can provide very limited quantitative measurements of the amount of the skin care product. It is believed that the use of the fluorescent tracers is much less operator dependent. Comparing Figs 7a, b and 8a, b, one can see that the initial slope in the spectroscopic data, Figs 7a and b, is more pronounced than in the mass measurements, Figs 8a and b. In particular, this can be clearly seen for the case of glycerin, Figs 7a and 8a. Such a behavior can presumably be explained by the analysis of what happens to the fluorescent particles after the application of the vaseline/gly-

cerin. First, the particles can be removed by an accident scraping (testing individuals were allowed to behave freely between the measurements). This, however, can explain the general decrease of the amount of the product and particles, but not the difference in the slopes. Secondly, the product is being adsorbed by the skin. This process is quite different for vaseline and glycerin. Vaseline is very viscous and greasy compared with glycerin. After sometime, it can clearly be seen that glycerin accumulates in skin crevices, Fig. 9 (regular light reflection image). It should be noted that it was virtually impossible to obtain a similar image for vaseline because of high reflectivity of residual amount of vaseline left on the cornea surface. Fluorescent images show accumulation of fluorescent particles in crevices for both glycerin and vaseline (not shown due to the lack of a high-sensitivity camera). However, this process is much faster for glycerin. Therefore, we can explain the fast

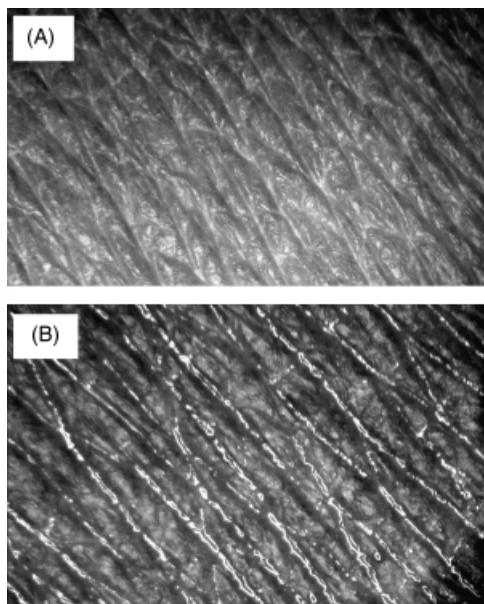


Fig. 9. High-magnification reflection optical images of the forearm skin. (a) Bare skin showing crevices/cracks with no glycerin applied. (b) Localization of glycerin at the crevices/cracks soon after application.

initial slope of Fig. 7a by the relatively rapid removal of glycerin (with particles) from the skin surface and its accumulation in the crevices. The subsequent saturation/slow decrease in signal after the initial slump is now naturally explained by the long life of glycerin and the particles inside the crevices. A similar process occurs for vaseline but at a slower rate.

In the end, it is worth stating that after soap washing, virtually no particles were left on the skin as was checked by means of the fluorescent microscope.

## Conclusion

The use of fluorescent silica colloidal particles is safe for topical applications, and can be used for the labeling and non-contact tracing of skin care products. Encapsulation of the dyes inside the silica particles and the relatively large sizes of the particles makes the topical application of the skin care products premixed with the silica colloids completely benign. Strong fluorescence of the particles ensures that only a very small amount is necessary to trace skin care products on the skin surface. This novel approach facilitates to monitor quantitatively the efficacy of skin care products with the least number of experimental errors. The similarity in the spectral analysis graphs and the scraped mass graphs shows that our approach of using fluorescent tracers is an

efficient method to quantify the dynamics of emollients and humectants on the skin. Analysis of difference in the spectral and scraped mass graphs reveals details of accumulation of the skin products in the crevices. The latter can probably be used for quantification of crevices and skin cracks.

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