Efficacy Evaluation of Skin Care Products Using PhabrOmeter

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Abstract

Current instrumental technology in evaluating performance of skin care creams is still rather limited and there are no industrial standard testing equipment, method and performance specifications for it.

In this paper, we report our attempt in using an instrument called PhabrOmeter for this purpose. PhabrOmeter is a commercialized instrument for sensory performance evaluation of textiles, leather, paper and nonwoven and has been designated by American Association of Textile Chemists and Colorists (AATCC) as a standard test method for textiles, AATCC TM 202 in 2013.

By adopting artificial skin samples treated with skin care creams, we have developed a procedure to apply this instrument for evaluation of skin care creams from sample preparation, measurement to data analysis and interpretation. The results using commercial skin care creams to demonstrate the feasibility and advantages of this instrument are provided.

Introduction

Owing to the growing global interest, the anti-aging movement, and the related technological developments, the global skin care industry's market value has been steadily rising for the past decades and the trend is proposed to continue into the future and the skin care industry is projected to be worth $102 billion by 2018 [1].

According to [2], consumers are not only demanding skin care products designed to target specific skin concerns but also have expectations for new technology that can address a multitude of skin issues with one product. Such concerns and overall skin performance are closely related to skin properties, but so far, skin care products are considered only influence the skin surface, and the specific mechanisms how the skin care products interreact and modify the skin properties, i.e., the cosmeceuticals, are still elusive and far from clear [3]. This work will target on development of an effective measurement approach to ascertain whether and how skin care products affect the skin properties that influence human perception of skin appearance.

Our skin is actually a rather complex laminated system [4, 5]. As illustrated in the right side of Fig. 1 [4], the outermost layer of the skin is termed the epidermis. The dermis and hypodermis are the other layers of skin that lie below the epidermis. Based on functions, the epidermis is divided into 5 sub-layers as in the left side of Fig. 1. The basale layer is the innermost layer of the epidermis situated just above the dermis. The columnar keratinocyte cells form a major part of stratum basale single layer where new cells are generated. The next layer up is called spinosum is a part of the immune system, scavenging for viruses and bacteria to keep the skin safe from infections. The third layer, the granulosum, is a protein structure containing either keratohyalin or lamellated granules. It plays a crucial role in the formation of keratin in the upper layers. Whereas the lamellated granules contain glycolipids that act as water sealants. This lucidum layer is usually detected in thick skin portions of the skin to protect these areas of the skin that are prone to friction and abrasion [4, 5].

The outermost layer of the epidermis, the stratum corneum, around 10% of the epidermis layer, is the body's front line against the outside environment, acts like a protective covering to keep the moisture trapped inside the skin, and is also the area that is most influenced by skin care treatments. The state of the stratum corneum governs the surface features of skin, particularly the frictional behavior and roughness, and plays a decisive role on skin tactile feeling. This water-proof, 10-micron thick layer comprises 15-20 layers of dead cells of keratin. The surface layers of epidermis often flake off due to environmental wear and tear [4, 5].

Water moisture has been known since 1952 to be a significant factor for skin health, when Irwin Blank first identified water's impact on stratum corneum plasticity [6]. Sufficient water content within the stratum corneum is essential for healthy, smooth, and elastic skin. Unfortunately, because of the normally much lower relative humidity of the outside environment than the internal parts of the body, there is a significant water content gradient within the stratum corneum. In other words, stratum corneum is constantly losing water to the ambient. This relates directly to the areas affected by the moisturizing cream. Water aids in corneocyte sloughing, preventing drying and flaky skin, and also maintains stratum corneum extensibility.

It has been established via both consumer experiences and skin research, that skin cream moisturizes and improves the feeling of skin [3, 7, 8]. Skin care treatments increase the barrier function of the stratum corneum to keep water moisture from leaving the body. They also function by providing natural moisturizing factors to restore the function of the intercellular corneosome and lipid structures. Many kinds of humectants, occlusives, emollients, and emulsifiers as the major active substances have been incorporated into skin cream, each playing a functional role in the efficacy of skin cream. Consequently, there are infinite combinations and concentrations of the ingredients in skin care treatments that have led to almost as many products [7, 8].

With so many products on the market and a continuously growing industry, there is a need for quality validation and control. To the detriment of consumer satisfaction and protection however, there are no established standard testing procedures to measure the efficacy of skin care products. There are instruments used by the industry that measure skin elasticity, water content, and frictional properties, but whether these tests are sufficient and how they related to skin properties remain elusive [7, 8].

Roughly there have two main groups of issues relating to skin care products. The first focuses on safety (including toxicity) of the products. Both FDA and FTC indeed have regulations [9] on skin care industry but only cover safety and fraud. "*"FDA does not have the legal authority to approve cosmetic products and ingredients (other than color additives) before they go on the market. We also do not have a list of tests required for any particular cosmetic product or ingredient. However, a manufacturer or distributor of a cosmetic is legally responsible for ensuring that a marketed product is safe when consumers use it according to the directions in the labeling or in the customary or expected way. FDA can take action against the manufacturer of a cosmetic on the market if we have reliable information to show that a cosmetic does not meet the legal requirement for safety."[10]*

The second, also the focus of this work, is on the evaluation or confirmation of the cosmetic efficacy of the products, i.e., the claims made by the manufacturers or marketers of the skin care products. That is, how do consumers to be assured that a certain facial cream can indeed make face softer, smoother and looks younger? In theory there are some incentives for manufacturers, to aspire for quality assurance of their products, due to the competitive nature of the industry's consolidated structure [1], provided that there are reliable approaches to validate them.

What to measure and how to do it

The most common and natural way to access the efficacy of a skin cream is to actually try it, i.e., the sensory evaluation, by expert grading or consumer panel surveying. Of course, this method shares the same problems as other sensory tests, including the inherent personal bias, low repeatability and lacking authorized references or accepted standards.

The next option is instrumental measurement. The most important and relevant properties in skin tactile feeling and visual appearance is related to the mechanics of the skin, and the pertaining descriptive terms often used include skin elasticity, skin smoothness and softness. (Although there are very strict definitions of these terms in engineering, however those are often not applicable in evaluating skin performance).

Skin elasticity is widely used to describe skin softness; The skin care industry and associated research assert that softer and more appealing skin has more elasticity or a lower elastic modulus [3, 11], even though in engineering, the two terms, i.e., softness and elastic modulus, don't inherently share such connection. Also elasticity alone doesn't fully encompass all the attributes that contribute to the tactile feeling of softness, and other surface features of skin, such as friction and roughness, have to be considered as well [12, 13].

There are some existing procedures and instruments used to evaluate these products, although none of them has been standardized as industry routine for efficacy assessment of skin care products. For instance, both industry and academic research have used instruments that measure visual effects, hydration, barrier function, and various mechanical properties [11, 14-17], as summarized in Table 1 and Fig. 2. Most commonly adopted techniques include skin indentation (including Cutometer, piezoelectric sensors or durometers) or extraction, often in the form of a hand-held device acting against the face of a person to measure the resistance. Another major type is the corneometers used for skin water content measurement. However as discussed below, all the samples before testing are conditioned in standard temperature and humidity rooms so that the water content in the samples maintains as constant, so that moisture measurement is not necessary in this case.

It must be noted that there are some inherent issues with the existing techniques and instruments. The first is that the use of expert visual grading or self-assessment brings forth the bias concerns of subjective evaluation. Although skin aesthetics are important for product marketing and consumer satisfaction, visual evaluations of skin do not encompass the tactile feeling of softness. The poor reliability and repeatability of such sensory evaluation methods are not suitable to the global scale of the skin care industry. The skin mechanics tests listed may be able to effectively determine the elasticity of the skin but the results do not take frictional effects into account. Water moisture is a significant contributing factor to skin's feeling, yet the skin softness cannot be fully described by the information of water moisture content or the rate of water loss within the skin. Research has shown that water moisture alters stratum corneum elasticity, roughness, and friction [3] [18, 19]; yet by measuring the water content alone, there is no way to determine how the water presence alters the tactile sense of the skin. Although skin aesthetics are important for product marketing and consumer satisfaction, visual evaluations of skin do not encompass the tactile feeling of softness. To collect the complete results from these tests, multiple methods would be needed—further complicating time, resources, and result analysis.

There are more specific problems shared by existing methods, including first, the difficulty in determining whether to test the entire human face, or just focus on certain key locations (themselves to be determined). Also, there is difficulty in collecting a repeatable data among population as the human face is extremely complex and unique to individuals. Knowing how many and what specific attributes to be tested is also necessary to make reliable and complete judgments. Consequently, continuous efforts have been conducted to look for more comprehensive and effective ways to characterize and measure such complex properties of skin [3, 14, 20]. Nonetheless, just from reviewing the current regulations and testing procedures, it is apparent there is an urgent need for an effective, reliable and regular approach for skin quality assurance and, eventually, standardization.

The artificial skin as the substrata

One related issue is the need for testing substrates. Ideal test would be directly on human skin.

The huge variability discussed above and virtually lacking supply of human skin however call for substitutes. Without a consistent substrate, it is too difficult to extract meaningful analysis from across all the skin research efforts.

Vitro-skin ®, manufactured by IMS, Inc., is a gelatin and protein based synthetic skin substrate designed to mimic the surface properties of human skin, and has been applied as a test substrate for the testing of sunscreen sun protectant factor (SPF), UVA and UVB protection, emollient and spreading etc. [21-23] [24].

For creating a possible standard for the evaluation of skin moisturizer efficacy, synthetic skin has many advantages over human skin. Synthetic skin does not require human subjects, eliminating the need for ethical review. Variables such as topography, rheology, and moisture retainment properties are uniform, allowing measurements to be more consistent and reliable. Such synthetic skin is also generally cheaper than human or artificial skin intended for medical purposes.

The key properties of Vitro-skin mentioned above include topography, critical surface tension, pH, and ionic strength. Each of these properties are critical for the representation of human stratum corneum's frictional and adhesion behavior with and without skin treatment. Critical surface tension is a way to characterize surface wettability by measuring the contact angle made between a liquid droplet and the substrate surface [25]. The pH of healthy skin is neutral and changes in pH can alter the effects of moisturizers [26].

Another key feature for a substitute for human skin is the mechanics. Human skin is highly pliable and conforming, a property termed drapability in textiles. As shown in Fig. 3, when a piece of fabric is hanging on a vertical rod tip, it drapes or turns into a wrinkled state under its own weight (Fig. 3a), reflecting the anisotropy in properties of the fabric due to various directional differences. We know this is also an essential attribute of skin [7], which enables the desirable covering of skin to face to, at least, controll our facial expression, as opposed to a normal sheet of paper or plastic film that can only bend over in one direction on the rod tip as in Fig. 3b. By the way, it is critical to differentiate the two phenomena: wrinkle is a multi-curvature deformation occurred simultaneously in more than one axial direction, whereas folding describes more appropriately the bending deformation of a uniaxial curvature. That is, wrinkling captures the inherent anisotropy in fabric performance whereas bending or folding are unable to do that.

For the test detailed in next section, the skin specimen is cut into circular shape and then thrusted by a force exerted at the specimen center; thus actually "isotropicizing" the measurement process to reduce any irregular directional variations.

A possible solution

Table II, Columns 1 and 2, summarize the challenges discussed so far in scientifically assess the efficacy of skin care products, corresponding to various approaches. The major problems include the subjective bias if sensory evaluation is involved; the inconsistence and poor repeatability between different testers, and also, multiple instruments are required for measuring all relevant properties.

A parallel issue in textile industry is the assessment of fabric sensory properties - after all clothing is often coined as the second skin of human body - including the tactile feeling (fabric hand) and visual attributes (drape and wrinkle) [27-29] and they are affected by various treatments and finishes. Besides, cloth-skin interactions are also closely intertwined during cloth wearing to cause changes in these sensory properties [30-33]. Recently an instrument called the PhabrOmeter provides a simple but effective method to measure the sensory attributes of planar, fibrous materials. The method encompasses tensile, bending, shearing, compression, surface roughness, and friction—all being related aspects of a fabric deformation when it's being touched. The instrument has shown to be effective that AATCC (American Association of Textile Chemists and Colorists) has adopted it is as a standard test instrument for measuring fabric hand [34]. More detailed information about the instrument can be found online at http://www.nucybertek.com/Default.aspx.

As discussed in [32, 33] skin is also a fibrous, planar material. Once pushed by pressure, it will go through similar complex multi-curvature deformations just as a fabric does in a thrust test in PhabrOmeter, of low, complex stresses with large deformation, and multi-curvature bending with nonlinearity and friction. The PhabrOmeter is able to provide objective information on a material's sensory attributes that are also key for understanding consumer satisfaction with skin care treatments. As shown in Table II, Column III, PhabrOmeter is able to handle all the issues and measures all related skin properties, except skin moisture content which will be discussed below. In addition, the range of properties that Vitro-skin mimics, makes the material a suitable testing substrate for the PhabrOmeter instrument as illustrated in Fig. 4., where Fig. 4a shows the overall of the PhabrOmeter system; a sample is pushed through the sensor in Fig. 4b; and the sample is exiting the sensor in Fig. 4c.

The test results of PhabrOmeter include the following [29]

- The Sample tactile properties
    1. *Smoothness*: resistance when you slide hand across the sample;
    2. *Resilience*: how easy you can wrinkle the sample with your hand;
    3. Softness: compressibility judged by squeezing the sample in your hand;

    For skin, "Softness" is often viewed as a combination of those effects [3].

- Relative hand value (RHV)

    When comparing differences between individual samples, the concept of distance is often useful, and a greater distance indicating a larger overall difference in properties. If a widely preferred sample is used, then the distances between other samples relative to the preset sample become indicators of performance preference in terms of the preset sample.
- The Sample visual properties
    1. Sample drape coefficient refers to the sample shape or profile when held at the center as in Fig. 3a, a quantitative index of the multi-curvature deformability of the sample.
    2. sample wrinkle recovery factor describes how complete a sample can recover from wrinkle deformation.

The presumed skin attributes in PhabrOmeter terms

As discussed before there are no established standard terms and testing procedures to measure the efficacy of skin care products. There are instruments used by the industry, but whether these tests are sufficient and how they related to skin properties remain elusive [7, 8].

Since we are considering using PhabrOmeter for skin test, we may go one step further to assume what tested by PhabrOmeter are also necessary and sufficient for describing skin sample properties, unless a counterexample is identified.

Therefore, by use of PhabrOmeter, we are able to measure the following features related to the sensory attributes:

- The skin tactile properties

Smoothness, *Resilience* and Softness

- Relative hand value (RHV)
- The visual properties: Sample drape coefficient

All of the terms are as defined in the last section.

Sample preparation

The Vitro-skin synthetic skin came in 21 cm by 26 cm sheets with a face side that mimics the stratum corneum (Fig. 5a). The PhabrOmeter requires samples to be 100 cm^2 circles; three samples can be made per sheet of Vitro-skin. A 100 cm^2 circle template was used to trace the sample size onto the Vitro-skin sheet and a 45 mm diameter rotary cutter was used to cut the samples (Fig. 5b).

The out-of-package Vitro-skin is in a dehydrated state and requires proper hydration Fig. 5c to exhibit its skin-like behavior in Fig. 5d. Hydration conditioning is done in a hydration chamber which was about 87% RH for 24 hours. Conditioning the Vitro-skin samples also eliminate another issue – the moisture effect. After the conditioning, all samples retain the their original moisture amounts so that it is no longer a variable influencing the test result. All tests are with 3 repeats each. To prevent hydrated Vitro-skin sample from sticking with the PhabrOmeter sample holder. All related parts of the instrument are made of non-sticking Teflon.

For practice, three different skin cream products, Aloe vera, Luminesce, Shiseido, were chosen as detailed in Table 3a. By using a special manual tool for calendaring, the creams are applied to the Vitro-skin samples with high uniformity.

Test result and analysis

Detailed information about sample uploading and testing can be found online at http://www.nucybertek.com/Default.aspx.

Fig. 6a shows a typical load-time curve when a sample is thrusted through the sensor of PhabrOmeter. The vertical axis represents the force required to push the sample through and the horizontal axis is the corresponding time. The curve offers a complete description of the entire test process. However for brevity, we can derive some characteristics and the first set of numerical data are the three most characteristic features from the curve, i.e., the Nominal initial slop ***S***, the curve peak value ***P*** and the area-under-peak ***A***; once the data reaches the peak, the sample has exited the sensor and in a free state, the curve after the peak (red line) is hence not useful.

The instrument repeatability

The first concern about the test results of PhabrOmeter is the repeatability, or the instrument consistence. Fig. 6b illustrates the result comparison of three blank original Vitro-skin samples, and the test repeatability can be checked visually by looking at the figures. Alternatively, the repeatability of the curve can be transformed into the repeatability of the three feature points. The test results of the curve repeatability for all cases are provided in Table 3b. The types of creams are on the first column, data in the table is the Coefficient Variation (C.V) values in percentage. The second row corresponds to the results for the original Vitro-skin samples. The maximum CV value is 3.37%, still smaller that 5%, the normally accepted limit for error.

The instrument sensitivity

After the repeatability, the next important parameter in measurement is the sensitivity of the instrument. Fig. 6c can be used to show that. By comparing with Fig. 6b where the blank original Vitro-skin samples were tested three times, Fig. 6c clearly differentiates the 4 curves corresponding to 3 creams and 1 original. The original sample shows the highest nominal slope ***S***, the highest peak value ***P*** and area value ***A.*** Collectively, the original Vitro-skin sample exhibits the stiffest behavior, requires highest force and energy to be tested. Once treated with cream, any of the three, the parameters all reduced and the one with Shiseido brought the most significant change.

It is clear that the test method is reliable so that the samples of the same group yield highly consistent curves; and sensitive to detect the skin property changes due to skin cream. More discussion about the comparison is in a later section.

Sample treated by different creams

To further explore the efficacy of the creams, we dissected Fig. 6c into 3 individual figures where the three curves of the creams were plotted each along with the original Vitro-skin sample in Fig. 7a, 7b and 7c.

It is seen that in Fig. 6c that the Aloe vera exhibited the least influence on the Vitro-skin. Fig. 7a meanwhile magnified the differences, the Aloe vera curve shows a less sheer initial slope, thus reducing the Resilience, a smaller peak and area values, a sign of a softer behavior.

Fig. 7c on the other hand displayed the opposite case where Shiseido exerted the most significant effect. The Shiseido curve appears below the Vitro-skin curve at nearly every effective point. The Luminesce curve or performance in Fig. 7b is in between the two.

More specific information can be derived from the numerical parameters in Fig. 8 provided by PhabrOmeter after the tests. Fig. 8a offers the results of the Relative Hand Value (RHV). If we chose the original Vitro-skin sample as the Reference, and calculate the distances between other samples and the reference, we can construct Fig. 8a. It confirms the differences of the influence by each cream, i.e., Shiseido > Luminesce > Aloe vera, and does it in a more definitive and firm way.

So far we only discussed the differences in efficacy of the creams, mentioned nothing about the preference (which cream performance “better”). Actually such preference is perceptive and highly personal; i.e., just because Shiseido shows the most impact doesn’t mean it is favored by everyone. Human preference cannot be accurately predicted, except in one case. If we know enough about the reference sample we used. If it is widely agreed by a given group that the original Vitro-skin sample without cream is the most unacceptable state, then the ranking given in Fig. 8a is in fact the ranking of the preference to the creams by the people in that group.

Besides the overall index, there are other parameters representing various sample attributes in the remaining figures. In these figures, the vertical axis denotes each individual attribute values in relative terms (unless calibration is done). The higher the value, the stronger the attribute.

For instance Fig. 8b compares the sample Resilience values. Although so far we know Shiseido brought the most significant changes to the Vitro-skin sample, the two are next to each other in both Resilience and Smoothness in Fig. 8d. Situation only changed in Softness in Fig. 8c where the two samples are just opposite to each other. Whereas for cream Aloe vera which is shown to be the least effective. It takes mediocre values in both Resilience and Softness but the highest value in Smoothness – as it is known for. This is interesting and enlightening that the relationship between the individual attributes and the overall performance is so complex. It also demonstrates that the combination of both graphical and numerical results presents a powerful tool for the cream evaluation.

Now if we go back to Table 3a, there seems no correspondence between the listed prices and the efficacy of the creams discussed, opening a possibility of using this new tool for product pricing policies.

Conclusions

This PhabrOmeter-based assessment system for skin cream efficacy has demonstrated its feasibility and power. It is reliable so that the samples of the same group yield highly consistent results; and is sensitive to detect the skin property changes due to treatment by skin cream.

As the PhabrOmeter is already an AATCC standard for fabric sensory evaluation, by adopting artificial skin as the substrate and treated with commercial skin care creams, we have developed a procedure to apply this instrument for evaluation of skin care creams, from sample preparation, measurement to data analysis and interpretation. It is a technology readily available.

It is found from the results that the relationship between the individual attributes and the overall performance of skin is complex, and the combination of both graphical and numerical results presents a powerful tool for cream evaluation.

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