

Skin Moisturizers. II. The Effects of Cosmetic Ingredients on Human Stratum Corneum

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Synopsis—The four parameters described in Part I of this study, i.e., elastic modulus, relaxation function, water absorption, and water vapor transmission, have been used to study the effect of typical COSMETIC INGREDIENTS on human STRATUM CORNEUM. The elastic modulus and the stress relaxation modulus are useful measures of the ability of various cosmetic materials to alter the VISCOELASTIC BEHAVIOR of stratum corneum. It has been demonstrated that typical cosmetic HUMECTANTS increase the rate of transepidermal water loss *in vitro*, and an attempt is made to explain this phenomenon.

INTRODUCTION

A variety of humectants and of occlusive lipids has been used for many years to improve human skin and to protect it against damage, even though the principles underlying these approaches to skin treatment were not clearly understood. Blank showed in 1952 how important water is to the well-being of human skin and, in effect, established a rational basis for these time honored methods for skin conditioning (1). In his very thoughtful review, Chudzikowski comments on the undesirability of highly occlusive barriers because they have a tendency to lead to edema; he also rejects the traditional treatment of dry skin with humectants because they will absorb moisture not only from the air but also from the skin (2). It is apparent, therefore, that the cosmetic benefits of either treatment are debatable and that basic knowledge on how skin moisturizers work is lacking.

In the first part of this study, *in vitro* methods for determining the response of human stratum corneum to moisture were developed. It is the purpose of this second part to describe the influence of common cosmetic moisturizers on the properties of stratum corneum.

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EXPERIMENTAL PROCEDURES

The techniques are those described in Part I (3) with minor modifications if required. Generally, strips of stratum corneum (with the attached tabs) were immersed for one hour into the test material or solution. Thereafter the strip was floated onto a stainless steel wire mesh, drained, and carefully blotted. The strip was then air-dried and placed into the appropriate relative humidity chamber for at least 24 hours before testing. Sometimes, the test substance was applied to the stratum corneum with a cotton swab. Any excess was carefully blotted off before the stratum corneum was conditioned.

For the determination of water sorption by humectants, 50% aqueous solutions of the humectants were applied to small preweighed pieces of Gelman Type A glass filter paper. After conditioning at 0% RH, the weight of humectant was determined and the weight gain at a given RH was based on this "dry" weight. The glass filter paper was shown to absorb less than 1% of water at 90% RH, and this sorption was generally neglected.

RESULTS AND DISCUSSION

Mechanical Properties

Many cosmetic materials are reported to soften skin and to act as emollients. It was expected, therefore, that these materials would exert some influence on the mechanical properties of stratum corneum. Of particular interest is glycerol which is widely used by cosmetic formulators as a humectant and skin moisturizer. It is generally recognized (2) that glycerol is hygroscopic and will absorb water until it reaches equilibrium with the ambient RH. Glycerol has been employed for many years to "heal" chapped skin, and this effect is attributed to its ability to hold water in contact with the skin.

Values of the modulus AxE obtained at 22°C on strips of stratum corneum immersed in mixtures of glycerol and water are summarized in the curve shown in Fig. 1. The experimentally obtained values of AxE are normalized by dividing them by AxE of the same strip of stratum corneum immersed in distilled water to yield the plotted value of E_n . The results indicate that glycerol does not increase the elasticity of stratum corneum by itself but actually stiffens the stratum corneum at concentrations above about 30%, possibly by removing stratum corneum-hydrating water. These results are in accord with Blank's findings that water is the only plasticizer of horny material (4).

It was considered possible that the interaction of the stratum corneum/glycerol/water system under investigation was temperature sensitive. In order to study this aspect, the effect of temperature on the value of AxE was first determined by extending strips of stratum corneum, taken from the same specimen, under water maintained at various temperatures between 2° and

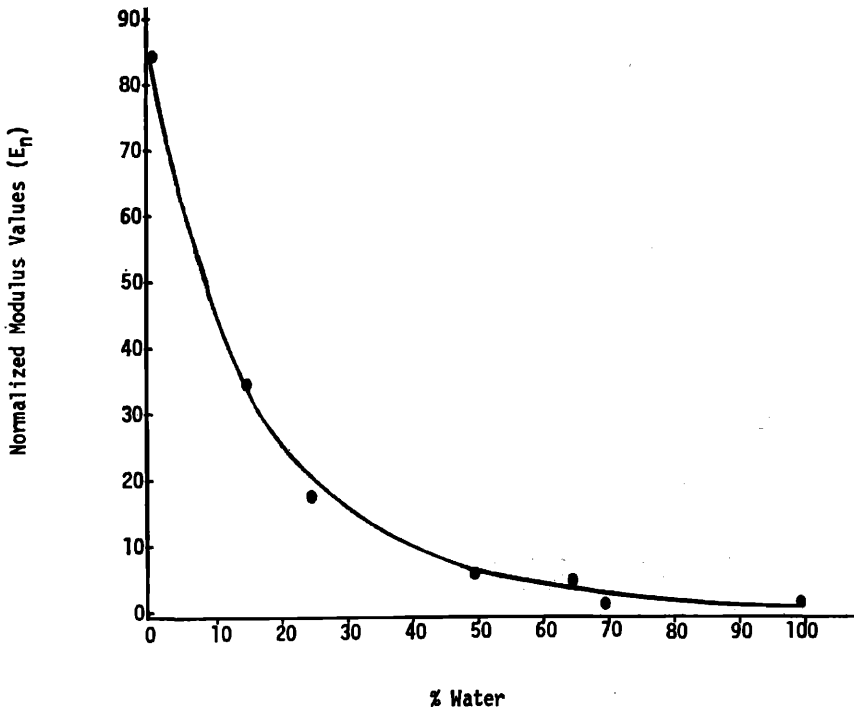


Figure 1. Effect of water concentration on normalized modulus values of stratum corneum (extended in glycerol/water mixtures at 22°C)

37°C. The values were divided by the value of AxE at 37°C under water, and the results are included in Fig. 2. It is apparent that the extensibility of human stratum corneum under the conditions of this experiment (immersed in water) shows very little change between 37°C and about 5°C. Middleton and Allen (5) also observed only a modest change in extensibility of guinea pig foot pad stratum corneum between about 20° and 40°C under different experimental conditions (in air of RH between 60 and 80%). Below about 5°C, stratum corneum appears to be stiffer, i.e., harder to stretch.

Figure 2 also includes the results of stretching in a solution of 1:1 water: glycerol (wt/wt) and a solution of 6M potassium iodide. The plotted data points were obtained by dividing the AxE values by the AxE values found at 37°C in the respective solutions. Glycerol was selected as a typical humectant, while potassium iodide (6M) is known to break the structure of water (6). In view of the similarity of the results, it is likely that the effect of glycerol is due to the breaking of the water structure in the stratum corneum; this might reduce hydration of the protein and make the stratum corneum stiffer or more difficult to stretch at temperatures below 18°C. The temperature dependence of stratum corneum elasticity observed here is probably too low

Table I
Elastic Modulus and Relaxation Function of Treated Stratum Corneum

Material	Elastic Modulus			Relaxation Modulus		Effect of Treatment ^f
	Control E_{0xA}	Treated E_{0xA}	Effect of Treatment ^a	Control ^b $\left(\frac{\log E_{0xA}}{\log t}\right)$	Treated ^b $\left(\frac{\log E_{0xA}}{\log t}\right)$	
0.1N NaOH	2085 ± 25	689 ± 180	++	0.040	0.040	o
0.1N HCl	2085 ± 55	751 ± 231	++	0.040	0.040	o
4% glycerol	826 ± 40	798 ± 42	o	0.043	0.072	+
50% glycerol	320 ± 42	230 ± 15	(+)	0.029 ^d	Curved	
1.00% glycerol	320 ± 42	254 ± 27	(+)	0.029 ^d	Curved	
50% propylene glycol	621 ± 16	500 ± 35	(+)	0.043	0.076	+
4% sodium pyrrolidone carboxylate	732 ± 82	88 ± 27	++	0.038	0.101	++
Light technical mineral oil	411 ± 35	524 ± 12	(-)	0.054	0.035	-
4% glucose glutamate	401 ± 5	416 ± 42	o	0.105	0.274	++
4% sorbitol	961 ± 196	632 ± 105	+	0.054	0.070	-
20% urea	409 ± 89	361 ± 55	o	0.053	0.098	-
4% Lanexol AWS®	2363 ± 301	1098 ± 361	+	0.032	0.032	o
Safflower oil	783 ± 174	922 ± 99	(-)	0.037	0.028	(-)
2% iodoacetic acid	1544 ± 260	1062 ± 158	+	0.043	0.041	o
4% glycine	1544 ± 260	1406 ± 170	o	0.043	0.049	o
4% PEI 18® (pH 8) ^f	1584 ± 81	786 ± 58	+	0.122	0.047	-
4% sodium lactate	848 ± 141	357 ± 57	+	0.057	0.065	o
4% potassium iodide	1584 ± 260	633 ± 99	+	0.122	0.191	+

^a++ = much more elastic; + = more elastic; - = less elastic; o = no change; (±) = marginal effect.

^bThe recorded values have an average error of about ± 4%.

^c+++ = much faster relaxation; ++ = faster relaxation; + = slower relaxation; o = no change; (±) marginal effect.

^dLarge deviation after 100 sec.

^eAn ethoxylated lanolin manufactured by Croda, Inc., New York, N.Y.

^fA polyethylene manufactured by Dow Chemical Co., Midland, Mich.

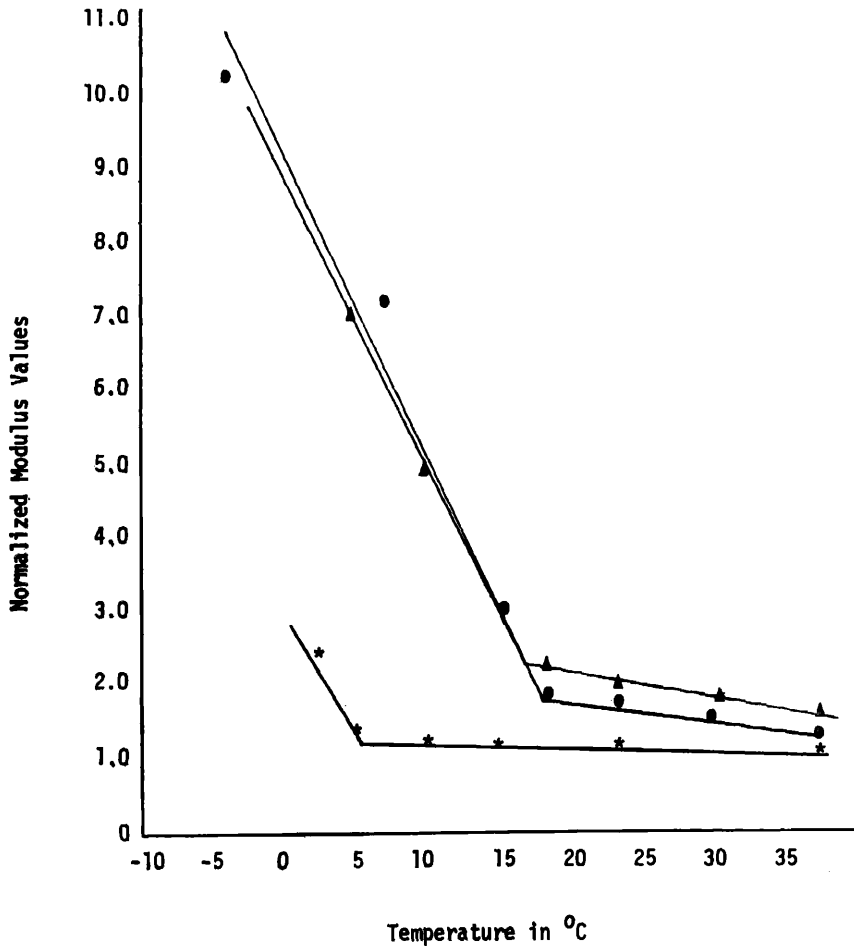


Figure 2. Effect of temperature on normalized modulus values. Stratum corneum extended under solution and normalized to the value for water at 37°C

—●—●—●—glycerol:water (1:1)
 —*—*—*—water
 —▶—▶—▶—6M potassium iodide

to exert any influence on chapping or related skin disorders, since the temperature of the face and hands does not reach 18°C until the air temperature drops to about -12°C [extrapolated from data of Phelps and Vold (7)]. However, the temperature of the lower extremities can reach 18°C at an ambient temperature as high as 19°C (8).

The effects of a variety of cosmetic ingredients and of a few chemical treatments on the physical properties of stratum corneum at 31% RH are summarized in Table I. In examining these data, it must be remembered that only horizontal comparisons are possible since the "control" and "treated" samples

are from the same stratum corneum specimen. A comparison within the various columns may lead to erroneous conclusions. A decrease in the elastic modulus below that of the control (recorded as +) is indicative of an increase in the elasticity of the stratum corneum. In the case of the stress relaxation modulus, an increase in the value over that of the control (recorded as +) describes the skin's ability to relieve a strain by viscoelastic response. The wide variations in the values for the controls are due to the fact that different specimens of epidermis were used, but this in no way reduces the value of the data. Each value recorded in Table I represents an average of 4 to 6 determinations on the same specimen of human epidermis. Treatment with either acid or base increases the elasticity of the stratum corneum substantially but does not appreciably alter its ability to relieve stress. Generally, the elastic and the stress relaxation moduli results after treatment parallel each other. Particularly noticeable is the remarkable "plasticizing" effect of dilute solutions of sodium pyrrolidone carboxylate and of sodium lactate. It is believed that the influence of cosmetic ingredients on the mechanical performance of stratum corneum correlates directly with their beneficial effect in skin preparations.

Moisture Absorption

The equilibrium moisture absorption of several important cosmetic moisturizers on glass filter cloth was studied after equilibration at several relative humidities. The data in Table II show that sodium pyrrolidone carboxylate and sodium lactate are capable of holding relatively large quantities of water even at intermediate relative humidities, i.e. between 50 and 70% RH. It proved impossible to conduct similar experimentation with propylene glycol because of its unexpectedly high volatility. Data for stratum corneum and some hydrophobic materials are included merely as a matter of orientation.

In view of the large effect of glycerin on the mechanical behavior of stratum corneum as a function of temperature (Fig. 2), it was considered conceivable that there is a specific interaction between glycerin, stratum corneum, and water which may increase the water-holding properties of stratum corneum. Similarly, the high hygroscopicity of sodium pyrrolidone carboxylate makes it possible that it too might impart some special water-holding properties to stratum corneum. In order to determine whether any such interactions occur, the isothermal absorptions of water by combinations of known weights of unextracted stratum corneum and glycerol or sodium pyrrolidone carboxylate were determined. The results shown in Table III clearly show that water absorption by stratum corneum is merely additive to that by the humectant. In other words, the moisture absorption by stratum corneum treated with a humectant is the sum of the absorptions of the individual components, with no evidence for any synergistic effects. These results are in agreement with the data reported by Fox *et al.* (9).

Table II
Equilibrium Moisture Absorption

Material	% Water Absorbed at			
	31% RH	52% RH	76% RH	90% RH
Stratum corneum	7	9	13	22
Glycerol	11	26	67	240
Sodium lactate	19	40	104	...
Sodium pyrrolidone carboxylate	17	45	210	...
Mineral oil	0.2	0.4	0.9	...
Safflower oil	0.2	0.5	1.0	...

Table III
Weight Gain (Water Content) of Stratum Corneum
and Stratum Corneum Plus Humectant

Sample	Initial Weight ^a (mg)	Amount of Water (mg) after Equilibration at	
		35% RH	75% RH
Stratum corneum	3.816	0.226	0.530
Glycerol ^b	3.058	0.339	2.058
Stratum corneum + glycerol			
Experimental	6.874	0.572	2.575
Calculated	...	0.565	2.588
Stratum corneum	3.784	0.183	0.515
Sodium pyrrolidone carboxylate ^c	3.468	0.720	3.488
Stratum corneum + sodium pyrrolidone carboxylate			
Experimental	7.252	0.892	3.892
Calculated	...	0.903	4.003

^aAt equilibrium with air at 0% RH.

^bU.S.P.

^cApplied from a 50% solution.

Water Vapor Transmission

The loss of moisture from the skin to the atmosphere is a continuous process, and excessive loss at low humidity and low temperatures is generally associated with skin dryness and chapping. It seemed particularly important to determine how cosmetic ingredients applied to stratum corneum might alter this tissue's ability to "transpire" water to an essentially dry atmosphere. Some typical *in vitro* water vapor transmission rates through stratum corneum are summarized in Table IV. This table also includes some common cosmetic humectants, some occlusive lipid materials, and Lotion #78. This last preparation, which is Formula 78 described by Barnett (10), was employed here because it was also studied *in vivo* by Berube *et al.* (11).

Table IV
In Vitro Water Vapor Transmission through Stratum Corneum

Material	Rate (mg cm ⁻² hr ⁻¹)		Ratio (Treated/Untreated)
	Untreated	Treated	
25% glycerol	0.264	0.518	1.96
4% sodium lactate	0.294	0.372	1.27
4% sodium pyrrolidone carboxylate	0.142	0.227	1.60
4% propylene glycol	0.223	0.267	1.20
Light tech. mineral oil	0.274	0.205	0.75
Safflower oil	0.309	0.281	0.91
Lotion 78 ^a	0.335	0.181	0.54

^aFormula 78 from Barnett (10).

The results obtained here are only directional in view of several experimental uncertainties: Experimentally, stratum corneum was first equilibrated in the diffusion cell against 0% humidity to yield an "untreated" rate. The material of interest was then applied to the exposed stratum corneum surface with the aid of a cotton swab. An effort was made to remove excess material while maintaining a continuous film, but there is no quantitation of the amount of substance actually remaining on the stratum corneum. The "treated" rate recorded in Table IV is the rate resulting after complete equilibration of the treated stratum corneum against the dry environment. As expected, lipid materials reduce water vapor transmission, whereas humectants cause a marked increase. The results with Lotion #78 confirm the *in vivo* data of Berube *et al.* who found that heavy application of this preparation was required to produce the occlusive effect (11). It is particularly noted that the small amount of sodium pyrrolidone carboxylate remaining on the stratum corneum after applying a 4% aqueous solution still causes a very large increase in the rate of water vapor transmission. These results clearly confirm the earlier data presented by Powers and Fox (12) that humectants increase transepidermal moisture loss.

Traditionally, humectants, such as glycerol, have been used for "improving dryness of skin and chapping." Published controlled clinical data attesting to the utility of humectants are missing, although the authors have access to a monadic clinical in-use study suggesting strongly that a preparation containing a high concentration of glycerol without any occlusive properties alleviates the dryness/chapping syndrome (13). It is difficult to reconcile the evidently beneficial effects of glycerol with its ability to increase transepidermal water loss. Only a very tentative hypothesis is offered here: Stratum corneum is commonly thought of as a homogeneous layer of cornified epithelial cells. The assumption is probably incorrect, since the outer portion of the stratum corneum may have suffered some damage due to wear and tear and the dissolution of lipid- and water-soluble constituents. As a result, the outer

barrier to the evaporation of water from stratum corneum is not the top of the stratum corneum but lies somewhere between the topmost and innermost cellular layers of the stratum corneum. Glycerol is known not to penetrate stratum corneum appreciably and presumably its application will result in the formation of a layer at or near the top of this epidermal structure. By virtue of its hygroscopicity, glycerol will unquestionably attract water from the lower layers of the stratum corneum whenever ambient humidity conditions preclude absorption from the air. This will result in continuous migration of water molecules through all layers of stratum corneum towards the glycerol layer which, in turn, readily loses water to the atmosphere. The benefits derived from the application of glycerol then reside in its ability to move the evaporative layer of skin moisture from somewhere in the center of the stratum corneum to the very top of the stratum corneum.

CONCLUSIONS

1. The stress relaxation modulus and the elastic modulus are sensitive measures of the ability of various cosmetic treatments to affect the viscoelastic behavior of stratum corneum.

2. The water-holding capacity of a system comprising a humectant and stratum corneum is the sum of the component parts. No synergistic effect could be demonstrated.

3. The application of typical cosmetic humectants to the exposed side of the stratum corneum increases the rate of transepidermal water loss.

4. A model to explain the beneficial effects of a moisturizer on the surface of the stratum corneum is proposed.

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