

Human skin condition and its associations with nutrient concentrations in serum and diet^{1,2}

Esther Boelsma, Lucy PL van de Vijver, R Alexandra Goldbohm, Ineke AA Klöpping-Ketelaars, Henk FJ Hendriks, and Len Roza

ABSTRACT

Background: Nutritional factors exert promising actions on the skin, but only scant information is available on the modulating effects of physiologic concentrations of nutrients on the skin condition of humans.

Objective: The objective was to evaluate whether nutrient concentrations in serum and diet are associated with the skin condition of humans.

Design: A cross-sectional study was conducted in which data on serum concentrations of nutrients, dietary intake of nutrients, and the hydration, sebum content, and surface pH of skin were obtained from 302 healthy men and women. Skin condition was measured with the use of noninvasive techniques. Dietary intake was assessed with 2 complementary food-frequency questionnaires. Multiple regression analysis was used to evaluate associations of serum vitamins and carotenoids and of dietary micro- and macronutrients with skin condition.

Results: After adjustment for potential confounders, including sex, age, and smoking, statistically significant associations were shown in the total population between serum vitamin A and skin sebum content and surface pH and between the dietary intake of total fat, saturated fat, monounsaturated fat, and skin hydration. Monounsaturated fat intake was also associated with surface pH. Associations between serum β -cryptoxanthin and skin hydration and between surface pH and fluid and calcium intakes were observed in men only.

Conclusion: Several associations between nutrients in serum and diet and skin condition were observed, indicating that changes in baseline nutritional status may affect skin condition. *Am J Clin Nutr* 2003;77:348–55.

KEY WORDS Skin condition, sebum, hydration, pH, diet, vitamins, carotenoids

INTRODUCTION

In recent years, functional foods claiming health benefits have increased enormously. Many products have already entered the market, and applications range from the effects on neurologic and psychological conditions to effects on cardiovascular function, the immune system, cancer, and aging. The food industry has become increasingly interested in the field of skin care.

Skin condition, in general, is defined by a combination of surface texture, color, and physiologic properties, such as hydration, sebum content, and surface acidity. The presence of an adequate amount of water in the stratum corneum, ie,

hydration, is important for a general appearance of a soft and smooth skin. Sebum, which is secreted by the sebaceous glands together with other epidermal lipids, helps maintain hydration of the skin by providing a protective lipid layer on the skin surface that reduces fluid loss through the epidermis. Moreover, skin lipids and amino acids contribute to surface acidity, and a low pH protects the skin from pathogens. These skin characteristics are known to be affected by endogenous and environmental factors, including aging, exposure to sunlight, chemicals, and mechanical damage (1–3). Moreover, food intake—particularly the consumption of fat and sweet and spicy food—is frequently mentioned as influencing skin condition, although scientific proof of this is scarce. To maintain and improve skin condition, a wide variety of skin-care products are on the market. However, many skin problems originate from endogenous sources and may have underlying dietary causes. Therefore, the influence of nutritional factors on the skin has received increasing attention (4, 5).

Part of our knowledge of the relation between nutrients and skin comes from the incidence of skin problems as a result of nutritional deficiencies. Deficient consumption of several vitamins and essential fatty acids has clear cutaneous manifestations (6). Although the frequency of nutritional deficiencies is low in developed countries, imbalance and incomplete diets as a result of disease, aging, and the abuse of alcohol and drugs may influence health status and thereby affect skin condition (7, 8). Optimization of the diet may not only prevent skin disorders but may also improve skin condition. Intervention studies investigating the effects of oral supplementation with relatively high doses of vitamins, trace minerals, and fatty acids have indicated the possibility that dietary factors can modulate skin function. The photoprotective potential of antioxidants (9), the effects of micronutrient supplementation on the (skin) immune system (10), and the modulating effects of fatty acids

¹ From the Department of Nutritional Physiology (EB, IAAK-K, and HFJH), the Department of Nutritional Epidemiology (LPLvdV and RAG), and the Department of Target Organ Toxicology (LR), TNO Nutrition and Food Research, Zeist, The Netherlands.

² Address reprint requests to E Boelsma, TNO Nutrition and Food Research, Department of Nutritional Physiology, PO Box 360, 3700 AJ Zeist, Netherlands. E-mail: boelsma@voeding.tno.nl.

Received November 8, 2001.

Accepted for publication April 10, 2002.

on skin disorders (11) have been the subject of a considerable number of studies (reviewed in reference 5).

Information on the effects of dietary factors on skin condition in humans and on the possibility that skin condition can be manipulated via changes in dietary factors, however, is scarce. Only one recent study that we are aware of supports this possibility (4). In that cross-sectional study (4), skin wrinkling in sun-exposed skin sites in elderly people was influenced by the consumption of different types of foods. The aim of the present study was to evaluate the association of skin hydration, the sebum content of the skin, and the pH of the skin surface with dietary and serum nutrient concentrations in a cross-sectional design with 302 healthy volunteers.

SUBJECTS AND METHODS

Subjects

Three hundred two male and female subjects aged 18–75 y participated in the study. The subjects were recruited from the pool of volunteers at TNO Nutrition and Food Research (Zeist, Netherlands) and through advertisements in the local and regional newspapers and on television. The cross-sectional data analyzed in the present study were obtained from an intervention study designed to test an unrelated hypothesis. All measurements were performed in the summer (from 28 June 1999 to 9 September 1999). In the intervention study, subjects were ranked according to their intakes of fruit and vegetables over the previous month. Consumption was based on responses to a questionnaire requesting data on fruit and vegetable consumption, including fruit juices. Subjects in the highest quintile of fruit and vegetable consumption and those in the lowest tertile (calculated in the total group) were selected. Subjects who were pregnant or lactating, were receiving anticoagulant therapy, or had a serum cholesterol concentration >7.5 mmol/L or a triacylglycerol concentration >2.3 mmol/L (if not stabilized with treatment for hypercholesterolemia or hyperlipidemia) were excluded. Informed consent was obtained from all subjects. The study was approved by the TNO Medical Ethics Committee and was conducted according to Good Clinical Practice guidelines at TNO Nutrition and Food Research.

Skin variables

Noninvasive biophysical methods were used to assess skin condition. Before the skin measurements were made, the subjects remained in a sitting position for ≥ 10 min in an environmentally controlled room (temperature: $22 \pm 2^\circ\text{C}$; relative humidity: 40–60%) to acclimatize to ambient conditions. The subjects were kept relaxed during the measurements. All measurements were performed in triplicate. The subjects were asked to not use any cosmetics or soap for ≥ 16 h before the measurements were made and were asked to not wash the measurement sites on the test day. Skin hydration and skin-surface pH were measured on the right arm. Sebum content was measured on the forehead.

Skin-surface pH

Skin-surface pH was determined with a Skin-pH-meter PH900 (Courage and Khazaka Electronic GmbH, Cologne, Germany). Data were provided as pH values with an accuracy of 0.1. Before

each measurement was made, the flat glass electrode was rinsed with distilled water, and any excess water was shaken off. Subsequently, the electrode was placed onto the volar forearm with slight pressure for 3 s.

Skin hydration

Skin hydration was measured with a Corneometer CM825 (Courage and Khazaka), which measured the capacitance of the skin electrically to a depth of ≈ 30 – 40 μm . Data were given in arbitrary units (AU). The probe (49 mm^2) was placed onto the volar forearm, and a measurement was taken and displayed after the correct pressure was achieved.

Skin sebum content

The Sebumeter SM810 (Courage and Khazaka) was used to assess the sebum content on the forehead. Disposable opaque plastic tape (64 mm^2) was pressed onto the forehead for 30 s with a slight pressure to collect the sebum. The resulting increase in transparency of the tape was measured with the use of an optoelectronic method. The displayed value corresponded to the sebum amount on the skin surface in $\mu\text{g}/\text{cm}^2$.

Serum variables

The following variables were analyzed in fasting blood samples: retinol (vitamin A), α -tocopherol (vitamin E), ascorbic acid (vitamin C), α -carotene, β -carotene, lycopene, lutein, zeaxanthin, and β -cryptoxanthin.

Sampling

For the analysis of carotenoids, retinol, and α -tocopherol, fasting blood samples were collected in tubes containing clot activator and gel (Vacutainer; Becton Dickinson, Franklin Lakes, NJ). These tubes were immediately stored in a closed light-tight box to avoid the breakdown of carotenoids by ultraviolet light. The tubes were centrifuged within 15–30 min after collection at $\approx 2000 \times g$ for 10 min at $\approx 4^\circ\text{C}$ to obtain serum. After centrifugation, the serum was removed and stored at $\approx -80^\circ\text{C}$. All handling of serum before storage was performed in subdued light.

For the analysis of vitamin C, blood was collected in tubes containing lithium heparin (Vacutainer; Becton Dickinson). A 0.5-mL aliquot of blood was added to 2 mL metaphosphoric acid (50 g/L; Mallinckrodt Baker, Deventer, Netherlands) before freezing at $\approx -80^\circ\text{C}$ to prevent the breakdown of vitamin C during storage.

Analysis

Carotenoids, vitamin A, and vitamin E were measured in serum with the use of HPLC followed by fluorimetric detection (12). This HPLC method allowed simultaneous detection of carotenoids, retinol, and tocopherols and their isomers. Vitamin C was analyzed with an HPLC system with fluorimetric detection (12).

Dietary intake

Habitual dietary intake over the previous 3 mo was assessed with 2 complementary semiquantitative food-frequency questionnaires (13, 14). The first food-frequency questionnaire consisted of 142 questions to assess dietary intake, excluding fruit and vegetable consumption. The second food-frequency questionnaire consisted of 69 questions about fruit and vegetable intakes and 4

TABLE 1
Characteristics of the study population and skin variables per category¹

Characteristic	Sebum content	Surface pH	Hydration
	$\mu\text{g}/\text{cm}^2$		AU
Total ($n = 302$)	147 \pm 71	4.8 \pm 0.4	36 \pm 7
Sex			
Men ($n = 149$)	161 \pm 69 ²	4.7 \pm 0.4 ²	37 \pm 7 ²
Women ($n = 153$)	133 \pm 70	5.0 \pm 0.4	34 \pm 6
Age			
<35 y ($n = 99$)	138 \pm 65	4.8 \pm 0.5	34 \pm 6 ³
35–49 y ($n = 102$)	146 \pm 71	4.9 \pm 0.5	36 \pm 7
≥ 50 y ($n = 101$)	155 \pm 76	4.8 \pm 0.4	37 \pm 6
Smoking status			
Nonsmoker ($n = 214$)	140 \pm 70 ⁴	4.8 \pm 0.4	36 \pm 7
Smoker ($n = 88$)	162 \pm 71	4.8 \pm 0.4	35 \pm 5

¹ $\bar{x} \pm \text{SD}$. AU, arbitrary units.

²Significantly different from women, $P < 0.001$.

³Significantly different from ≥ 50 y, $P < 0.05$.

⁴Significantly different from smoker, $P < 0.001$.

questions about supplement use. The combination of both questionnaires precluded the counting of some food items twice. From these questionnaires, the habitual consumption of total energy, macronutrients (carbohydrate, protein, total fat, saturated fat, monounsaturated fat, and polyunsaturated fat), cholesterol, fiber, and micronutrients (β -carotene, calcium, and vitamins A, C, and E) was determined. In addition, total fluid intake (including mineral and tap water) was determined to evaluate its possible association with skin condition.

Statistical analysis

The statistical analysis was carried out with the SAS statistical software package SAS/STAT (version 6; SAS Institute, Cary, NC). Pearson's correlation coefficients were calculated between skin variables. Analysis of variance and t tests were used to evaluate the differences in skin variables by categorical variables (ie, sex, age category, and smoking status). The interaction between sex and age was tested with the use of general linear models. Subgroup analyses were performed only if the interaction was significant. The level of significance was set at $P < 0.05$. The normality of the variables was tested. Because all of the variables were normally distributed, no additional transformation was necessary. To evaluate associations between skin variables and nutrient concentrations in the serum and diet, linear regression analysis was performed by using general linear models. Model assumptions were tested, including Cook's distance and the normal distribution (Studentized) of residuals. First, crude univariate linear regression models were performed with hydration, sebum content, or skin-surface pH as dependent variables and with individual nutrients in the serum or diet as independent variables. Second, multiple linear regression was used to evaluate associations of nutrient concentrations in the serum or diet with skin variables, with adjustment for potential confounders (sex, age, and smoking status) that generated adjusted general linear models. Interactions with sex, age, and smoking status were initially included in the model. Stratified, adjusted models were analyzed when a statistically significant interaction term was noted. Nonsignificant interaction terms were omitted from the model. The results are presented as means \pm SDs.

RESULTS

Skin-condition variables in the study population

An approximately equal number of men and women participated in the study: 149 men (age: 42.9 \pm 15.2 y; range: 19–73 y) and 153 women (age: 41.7 \pm 13.1 y; range: 18–73 y). Thirty-two percent of the men and 27% of the women were smokers. Three age categories were distinguished: younger (26.3 \pm 5.0 y; range: 18–34 y; $n = 99$), middle age (41.4 \pm 4.4 y; range: 35–49 y; $n = 102$), and older (58.1 \pm 6.1 y; range: 50–73 y; $n = 101$). Smokers constituted 30% of the younger, 27% of the middle age, and 30% of the older age groups.

Surface pH, hydration, and sebum content were significantly different between men and women ($P < 0.001$); men had lower pH values but higher hydration values and sebum contents (Table 1). Surface pH and sebum content were not significantly different between the age categories, but hydration was significantly lower ($P < 0.05$) in the younger age group than in the middle age and older age groups. A significant interaction between sex and age ($P = 0.014$) was shown only for sebum content (data not shown). Significantly ($P < 0.05$) higher values for sebum content were shown in the older age group: 184 \pm 68 $\mu\text{g}/\text{cm}^2$ in men and 120 \pm 70 $\mu\text{g}/\text{cm}^2$ in women. Men in the middle age group tended to have a higher sebum content (161 \pm 64 $\mu\text{g}/\text{cm}^2$) than did women (135 \pm 75 $\mu\text{g}/\text{cm}^2$), whereas men in the younger age group tended to have a lower sebum content (135 \pm 66 $\mu\text{g}/\text{cm}^2$) than did women (142 \pm 64 $\mu\text{g}/\text{cm}^2$) (data not shown). The differences in these latter 2 age groups, however, were not significant. No interaction between sex and age was found for surface pH and hydration (data not shown). The mean sebum content was significantly higher in smokers than in nonsmokers ($P < 0.001$).

In the total population, surface pH and hydration were negatively correlated ($r = -0.20$, $P < 0.05$), as were surface pH and sebum content ($r = -0.20$, $P < 0.05$). No correlation was shown between sebum content and hydration. Within-subject variances for the skin variables were smaller than the between-subject variances, and the ratios of between variance to within variance for pH, hydration, and sebum content were 10, 5.6 and 6.9, respectively.

Serum nutrients

In the regression analysis, serum vitamin C was inversely associated with hydration in the crude model but was not after further adjustment for sex, age, and smoking status. Serum vitamin E concentrations, either corrected or not corrected for total cholesterol concentrations, were not associated with skin condition. Serum vitamin A was a predictor of sebum content and surface pH in the adjusted models (Table 2). No significant interactions between vitamin A and sex, age, or smoking status were found. An increment of 0.1 $\mu\text{mol}/\text{L}$ in the serum vitamin A concentration (4.8% of the mean) was associated with a 2.03- $\mu\text{g}/\text{cm}^2$ lower sebum content (1.4% of the mean; Figure 1). A significant crude association was found between vitamin A and surface pH (Figure 2). This association was not significantly affected by inclusion of sex, age, and smoking status in the model. An increment of 0.1 $\mu\text{mol}/\text{L}$ in the serum vitamin A concentration was associated with a decrease in surface pH of 0.01 (0.3% of the mean).

With respect to the serum carotenoids, only β -cryptoxanthin was associated with skin condition, but it predicted hydration in

TABLE 2

Linear regression coefficients (β) and SEs for serum nutrients and skin-condition variables¹

Nutrient	Serum concentration ²	Sebum content ³	Surface pH ³	Hydration ³
	$\mu\text{mol/L}$	$\mu\text{g/cm}^2$		AU
Vitamin C	54.9 \pm 15.6 (46.2–64.5)	–0.01 \pm 0.03	0.00 \pm 0.00	0.00 \pm 0.00
Vitamin E	26.3 \pm 5.5 (22.5–29.5)	–0.11 \pm 0.08	–0.00 \pm 0.00	–0.00 \pm 0.01
Vitamin A	2.10 \pm 0.44 (1.83–2.32)	–2.03 \pm 0.90 ^d	–0.01 \pm 0.01 ^d	0.08 \pm 0.08
Lycopene ⁵	0.30 \pm 0.17 (0.19–0.40)	–1.26 \pm 2.51	–0.02 \pm 0.02	
Younger age				–0.36 \pm 0.47
Middle age				0.65 \pm 0.34
Older age				0.63 \pm 0.43
β -Carotene	0.28 \pm 0.18 (0.15–0.37)	0.03 \pm 2.28	0.01 \pm 0.01	0.34 \pm 0.21
Lutein	0.16 \pm 0.07 (0.11–0.20)	4.82 \pm 5.84	–0.06 \pm 0.04	0.45 \pm 0.54
β -Cryptoxanthin ⁶	0.15 \pm 0.10 (0.09–0.18)	1.38 \pm 3.98	–0.03 \pm 0.02	
Men				1.54 \pm 0.68 ^d
Women				–0.28 \pm 0.44
Zeaxanthin ⁷	0.046 \pm 0.018 (0.033–0.058)	7.14 \pm 22.12	–0.14 \pm 0.13	–0.10 \pm 2.02
α -Carotene	0.058 \pm 0.045 (0.032–0.067)	0.68 \pm 9.09	–0.04 \pm 0.05	0.48 \pm 0.84

¹Model: skin variable = nutrient in serum (0.1 $\mu\text{mol/L}$) + sex + age (y) + smoking status (yes or no). AU, arbitrary units.² $\bar{x} \pm \text{SD}$; range (25th to 75th percentiles) in parentheses.³ $\beta \pm \text{SE}$.⁴ $P < 0.05$.⁵Significant interaction term lycopene \times age for hydration: adjusted separate models for age categories.⁶Significant interaction term β -cryptoxanthin \times sex for hydration: adjusted separate models for men and women.⁷One subject had a very high zeaxanthin concentration of 0.167 $\mu\text{mol/L}$ and was excluded from the data set.

men only. A significant interaction term was noted for sex \times β -cryptoxanthin ($P < 0.01$). In a separate model for men, after adjustment for age and smoking status, an increment of 0.01 $\mu\text{mol/L}$ in the serum β -cryptoxanthin concentration (6.8% of the mean) was associated with an increase in skin hydration in men by 0.15 AU (0.4% of the mean; **Figure 3**). A significant interaction was shown for lycopene \times age ($P < 0.05$), but no significant association between lycopene and skin hydration was shown in separate models per age category.

Dietary nutrients

Surface pH, sebum content, and hydration were regressed on the dietary intake of individual micro- and macronutrients. Vitamin A and calcium intakes showed significant associations with surface pH. In the adjusted model, the interaction term vitamin A \times sex was significant. In separate models for men and women, an increment of 100 μg dietary vitamin A (8% of the mean) was associated with a significant increase in surface pH of 0.015 (0.3% of the mean) in women only; no association was found in men. In the

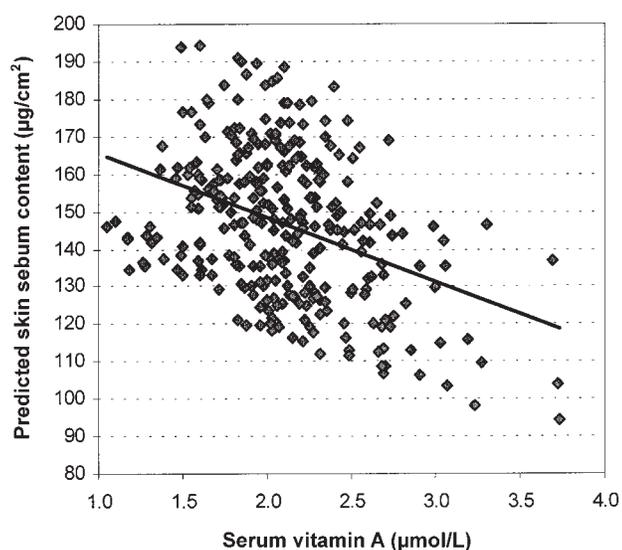


FIGURE 1. Association between increasing serum vitamin A concentrations and predicted skin sebum content in individual men (\blacklozenge) in the study population after fitting a model with sex, age, and smoking status.

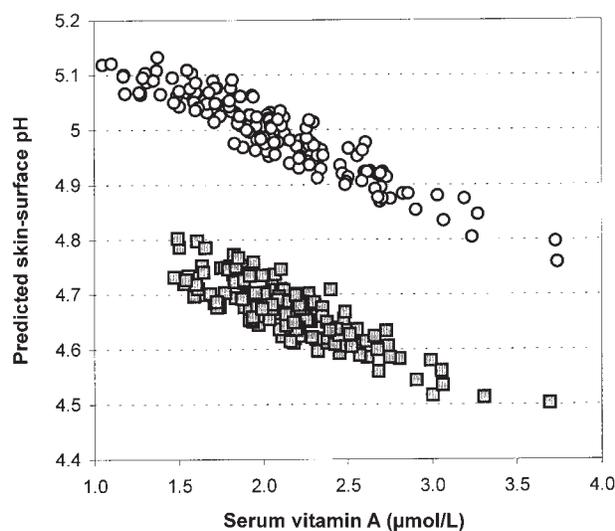


FIGURE 2. Association between increasing serum vitamin A concentrations and predicted skin-surface pH in individual men (\blacksquare) and women (\circ) in the study population after fitting a model with sex, age, and smoking status.

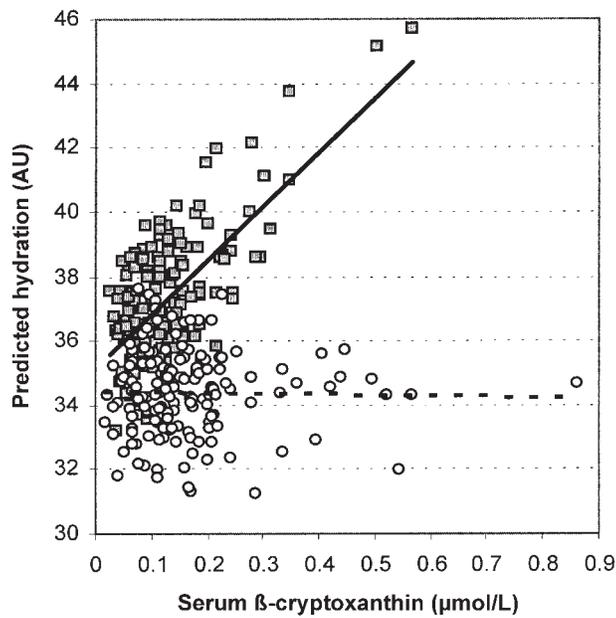


FIGURE 3. Association between predicted skin hydration β -cryptoxanthin in individual men (■) and women (○) in the study population after fitting a model with sex, age, and smoking status. The dotted line represents women and the straight line represents men. AU, arbitrary units.

adjusted model in which dietary calcium was used as the dependent variable, a significant regression coefficient (β) for the interaction term calcium \times sex was found. Evaluation of separate models for men and women resulted in a significant association between dietary calcium and surface pH in men; for every 10-mg increase in calcium intake (0.7% of the mean), the surface pH decreased by 0.001 (0.02% of the mean; **Table 3**). No associations were found between skin condition and intakes of vitamin C, vitamin E, and β -carotene.

The interaction term fluid \times sex was significantly different. In separate models for men and women, fluid intake was only inversely associated with surface pH in men; an increment of 100 mL in fluid intake (3.5% of the mean) was associated with a slight decrease in surface pH of 0.009 (0.18% of the mean); no association was shown for women (**Table 3**).

With respect to macronutrient intakes, the percentage of energy provided by protein, carbohydrate, and fat were calculated and were subsequently used as independent variables. No association between skin condition and intakes of protein or carbohydrate were found. After adjustment for sex, age, and smoking status, total fat intake was negatively associated with hydration (**Table 3**). The regression coefficients (β) of the interaction terms total fat \times sex, total fat \times age, and total fat \times smoking status were not significant. An increment of 10% of energy as fat was associated with a decrease in skin hydration of 1.74 AU. (4.8% of the mean). Furthermore, in adjusted models, intakes of saturated fat and monoun-

TABLE 3
Linear regression coefficients (β) and SEs for dietary intake of nutrients and skin variables

Nutrient	Intake ¹	Increment	Sebum content ²	Hydration ^{2,3}	Surface pH ²
			$\mu\text{g}/\text{cm}^2$	AU	
Micronutrients⁴					
Vitamin C ⁵	166 \pm 236 mg (85–175)	100 mg	0.07 \pm 1.72	–0.08 \pm 0.16	0.02 \pm 0.01
Vitamin E	15.0 \pm 20.2 mg (9.4–16.7)	100 mg	29.8 \pm 19.7	–0.38 \pm 1.83	0.23 \pm 0.12
Vitamin A ⁵	1.26 \pm 0.75 mg (0.71–1.51)	100 μg	–0.33 \pm 0.54	–0.04 \pm 0.05	
Men					–0.00 \pm 0.00
Women					0.02 \pm 0.01 ⁶
β -Carotene	2.94 \pm 2.24 mg (1.52–3.69)	1 mg	0.32 \pm 1.80	–0.07 \pm 0.17	0.00 \pm 0.01
Calcium ⁵	1378 \pm 635 mg (959–1687)	100 mg	0.29 \pm 0.64	0.08 \pm 0.06	
Men					–0.01 \pm 0.01 ⁶
Women					0.01 \pm 0.01
Cholesterol	236 \pm 86 mg (175–279)	100 mg	–0.67 \pm 4.87	–0.03 \pm 0.45	0.01 \pm 0.03
Fiber	28.0 \pm 10.5 g (20.9–32.4)	1 g	–0.04 \pm 0.39	0.01 \pm 0.04	–0.00 \pm 0.00
Fluid ⁵	2853 \pm 935 g (865–6471)	100 g	–0.12 \pm 0.42	0.06 \pm 0.04	
Men					–0.01 \pm 0.00 ⁶
Women					0.00 \pm 0.00
Macronutrients⁷					
Protein	16.5 \pm 2.7% (14.8–18.2)	10%	5.72 \pm 15.47	0.36 \pm 1.43	–0.08 \pm 0.09
Carbohydrates	49.2 \pm 6.6% (45.3–53.1)	10%	0.69 \pm 6.30	0.78 \pm 0.58	–0.05 \pm 0.04
Total fat	31.2 \pm 5.3% (27.6–34.5)	10%	0.36 \pm 7.62	–1.74 \pm 0.70 ⁶	0.07 \pm 0.05
Saturated fat	12.4 \pm 2.7% (10.7–14.1)	10%	–1.84 \pm 15.11	–2.79 \pm 1.38 ⁶	0.06 \pm 0.09
Monounsaturated fat	10.7 \pm 2.1% (9.4–12.3)	10%	–2.03 \pm 18.83	–4.17 \pm 1.72 ⁶	0.29 \pm 0.11 ⁶
Polyunsaturated fat	5.6 \pm 1.7% (4.4–6.3)	10%	9.78 \pm 24.25	–1.88 \pm 2.23	0.04 \pm 0.14

¹ \bar{x} \pm SD; range (25th to 75th percentiles) in parentheses.

² β \pm SE.

³AU, arbitrary units.

⁴Models: skin variable = micronutrient + sex + age (y) + smoking status (yes or no).

⁵Significant interaction with sex for surface pH.

⁶ $P < 0.05$.

⁷Models: skin variable = % of energy [(energy macronutrient/total energy) \times 100] + energy (kJ) + sex + age (y) + smoking status (yes or no).

saturated fat also appeared to predict hydration; an increase of 10% of energy as saturated fat and monounsaturated fat was associated with a decrease in hydration of 2.79 AU (7.8% of the mean) and 4.17 AU (11.6% of the mean), respectively. Moreover, intake of monounsaturated fat was significantly associated with surface pH in the crude and adjusted models; an increase of 10% of energy as monounsaturated fat was associated with an increase in surface pH of 0.29 (6.0% of the mean).

DISCUSSION

This cross-sectional study was performed to obtain information on associations between nutrients (serum concentrations and dietary intakes) and skin condition in humans. To our knowledge, this is the first study that investigated relations between nutrient concentrations in serum and skin condition. Only in the study by Purba et al (4) were associations between the dietary intake of several food items and skin wrinkling reported. The cross-sectional data in the present study were obtained from a large study group, and our aim was to evaluate the data as an initial inventory for an intervention study.

On the basis of measurements of skin condition, the men in the total population had significantly higher hydration values and sebum contents but significantly lower pH values than did the women. These differences in skin hydration between the sexes existed within each age category, and overall hydration was lowest in the younger subjects (<35 y). In contrast, previous studies reported that both sexes, when compared within the same age group, had similar hydration values at all anatomic sites studied (15–17). Although skin in the elderly is generally thought to be dry, data on skin surface hydration are contradictory (16, 18, 19). Use of instruments that are based on different measuring principles and that measure at different depths of the skin may account for the reported differences in the literature. In the total population, the sebum content did not change significantly with age, but a trend toward an age-related decrease in women and an age-related increase in men was observed. However, only in the older age group (≥ 50 y) was the sebum content significantly different between men and women. Our findings agree with those of previous studies, and the observed differences may largely be explained by the known age-related hormonal fluctuations in both men and women and the clear effects of hormones on sebaceous gland activity (17, 20, 21). Surface pH seems to be a rather stable variable that was lower in men than in women. Surface pH was not age-related, a finding that agrees with earlier studies (22, 23). Less acidic skin in women may be caused by hormonal differences that affect both sebum secretion and perspiration by apocrine sweat glands (22, 24).

Overall skin condition is the result of different processes, including sebum formation, hydration, and acidity. Skin lipids originating from sebaceous glands contribute to maintaining the skin in a hydrated state, and the unsaturated fatty acids prevent growth of bacteria on the skin and contribute to skin acidity. The “natural moisturizing factor,” which consists mainly of amino acids, also plays a role in skin hydration and acidity (25). Both sebum content and hydration correlated significantly with surface pH; an increase in sebum content and hydration was related to a decrease in surface pH.

To investigate whether an association exists between nutrients and skin, concentrations of nutrients in blood were first compared with skin hydration, sebum content, and surface pH. Although

nutrients were not measured in the skin itself, previous studies showed that the profiles of carotenoids, α -tocopherol, and retinoids in blood and skin are comparable (26, 27). Moreover, many vitamins have been shown in the skin and in skin-surface lipids derived from sebum and corneocytes, including vitamin A, α - and β -carotene, lycopene, lutein, zeaxanthin, and β -cryptoxanthin (28–30).

Regression analysis showed a consistent inverse association between serum vitamin A and sebum content and surface pH; a 4.8% increase in serum vitamin A was associated with a 1.4% decrease in sebum content and a 0.3% decrease in surface pH. Although the physiologic meaning of such changes is not clear, it is known that vitamin A plays an important role in the skin. Retinoids exert pronounced effects on keratinizing epithelia. In particular, synthetic retinoids have been shown to reduce sebaceous gland activity and to suppress sebum production (31, 32). Rollman and Vahlquist (33) showed that serum and skin concentrations of retinol were low in patients with acne vulgaris and slightly elevated in patients with ichthyosis vulgaris. Effects of vitamin A on skin acidity have not been reported, and it can only be speculated that pH can be modulated by involvement of the known biological mechanisms of action of vitamin A in the skin, including keratinization, sebaceous gland activity, and immunomodulation (34).

Only β -cryptoxanthin showed a significant positive association with skin hydration in men; a 6.8% increase in serum β -cryptoxanthin was associated with a 0.4% increase in skin hydration. On the basis of the 8% difference in baseline hydration between the men and the women, β -cryptoxanthin may not be a strong predictor of hydration. Whether β -cryptoxanthin exerts a unique biological effect on skin hydration remains to be established.

No associations between the nutrients consumed with the diet and sebum content were found. An increment of 10% of energy as total fat, saturated fat, and monounsaturated fat was associated with a decrease in hydration of 4.8%, 7.8%, and 11.6%, respectively. Specific fatty acids are known to be important for the preservation of the skin-barrier function and the structural integrity of the stratum corneum (35, 36). Although a direct influence of the consumption of fats on hydration is difficult to prove, it was previously shown that the fatty acid composition of the skin can be modulated by supplementation with certain fats and oils (37, 38). In addition, the total dietary fat intake and a high intake of monounsaturated fat have been shown to be negatively associated with photoaging (4). The positive effects of monounsaturated fat intake on surface pH can be explained by the association of monounsaturated fat with hydration and by the inverse correlation between hydration and surface pH. The lack of association between pH and total and saturated fat intakes was possibly due to the weaker associations between these 2 fats and hydration than between monounsaturated fat and hydration, which may have prevented associations with surface pH to be detected. Another possibility is that unknown interactions between dietary fats and hydration and pH may have been involved.

Although fluid intake is generally considered to be beneficial for skin health, the effects were likely weak because a 3.5% increase in fluid intake was associated with a 0.18% decrease in surface pH in men. The influence may have been too small to detect parallel associations with hydration. The association between calcium and surface pH was more difficult to explain and may have been of minor importance, because a 7% increase

in calcium intake was associated with a 0.2% decrease in surface pH in men only. Nevertheless, it is known that calcium plays an important role in the regulation of epidermal differentiation and desquamation of keratinocytes. Moreover, the presence of a calcium gradient over the epidermis has been shown to be linked to skin-barrier function because the calcium pattern is abnormal in several skin disorders with proliferation and differentiation defects (39). It is not clear why more nutrients were associated with skin condition in men than in women. However, it is possible that hormonal differences between the sexes played a role and that the skin condition of the women was probably altered already because women tend to use skin-care products more often than do men.

It should be taken into account that dietary intake does not necessarily correlate with the corresponding serum and tissue concentrations. Peng et al (26) previously showed that the relations between diet and blood and between diet and tissue were less strong than was the relation between blood and tissue. Common associations between dietary intake and other variables were underestimated because of the lack of accuracy associated with estimating dietary intake.

In conclusion, we showed that serum vitamin A concentrations and dietary intake of fats were associated with several characteristics of skin condition in the total population. Associations with serum β -cryptoxanthin and dietary intakes of fluids and calcium were found in men only. The present study provided data on a large group of subjects and is the first study to investigate associations between nutrient concentrations and skin condition. However, because only cross-sectional data were obtained, no causal inferences could be made between nutrient concentrations and skin condition. Because of the relatively large number of associations explored, some statistically significant associations may have occurred by chance. Moreover, blood contains many other biologically active nutrients, such as polyphenols and trace elements, that may influence skin health and many other organs. Studies are warranted to confirm our findings before any firm conclusions on the role of nutrition in skin care can be drawn. 

We thank the volunteers who participated in the study, Unilever Health Institute (Vlaardingen, Netherlands) for permitting the use of their data, and Wendy Broekmans for useful discussions.

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