Effect of hand hygiene regimens on skin condition in health care workers

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Frequent, repetitive exposure to hand cleansers can negatively impact the skin, particularly the protective stratum corneum (SC). We investigated the effects of synergistic test products (TP) and current products (CP) among health care workers (HCWs) during spring and winter. TP and CP were significantly different in quantitative measures of skin condition. TP resulted in improved condition versus CP at times during both trials. Compared with non-HCW control subjects, HCW hand skin was appreciably compromised. The skin was damaged at the start of a work cycle, suggesting that the SC damage did not recover during time off. In general, the skin was in poorer condition (higher grades) for CP at the end of a cycle than the start during both trials. The dryness scores were often lower for TP at the end of the cycle, suggesting an improvement in skin condition. During some winter cycles, the skin remained unchanged for TP and worsened for CP. For others, the skin improved with TP and was unchanged with CP. Dryness tended to decrease (improve) and erythema increased for TP. Overall, the use of TP consistently resulted in higher skin hydration compared with CP, indicating that product composition can significantly influence HCW skin condition. Regimens that minimize skin damage can improve condition while achieving skin disinfection. The findings emphasize the importance of providing hand hygiene products to minimize irritant dermatitis and maintain an effective skin barrier. Use of such products is expected to substantially impact and increase hand hygiene compliance. (Am J Infect Control 2006;34:S111-23.)

Control of hospital-acquired infections is a high priority for health care institutions world wide, particularly since approximately one third may be preventable.[1-3] Compliance with specific hand hygiene practices is effective for preventing health care-associated infections,[4] and the Centers for Disease Control and Prevention (CDC) 2002 guideline constitutes the current standard of care in the United States.[5] Despite the importance, compliance rates are approximately 30%.[6] Programs designed to improve compliance have been largely unsuccessful.[7-10] The primary reason for hand hygiene compliance failure is skin irritation and the deleterious effects of repetitive use of products and procedures.[11] The CDC guideline details the frequency and product types to reduce skin microflora. Visibly soiled hands are washed with soap (with or without antibacterial ingredients) and water. Antibacterial handrubs are indicated when visible soils are absent. Decontamination is to occur after contact with patient skin, fluids, equipment, and others. Health care institutions are to provide agents with low irritancy potential and products to minimize irritant dermatitis.[5]

The skin, particularly the stratum corneum (SC; the outermost layer of the epidermis), provides a physical, mechanical, and immunologic barrier to protect against environmental insults. The SC shields the Langerhans cells (immune function) from direct environmental exposure and, thereby, serves an essential function in infection control. However, frequent repetitive exposure of the skin to soap/surfactant cleansers and water has significant effects on the structure and function of the stratum corneum (SC) barrier, including disruption of the SC lipid bilayer architecture and increased permeability, penetration, and epidermal inflammation. The epidermis responds by up-regulating SC formation, resulting in hyperproliferation, a defective architecture, aberrant water-binding properties, insufficient hydration, and inadequate desquamation.[12-25] In the absence of environmental stressors, the SC turnover rate is 14 days.[26] However, the rate is significantly increased following chronic exposure to detrimental surfactants.[27] A damaged barrier is more susceptible to penetration by environmental insults, including microorganisms. The relationship between skin damage and bacteria counts was investigated, and, as damage increased, total bacteria counts were higher.[28] In the strictest sense, compliance with the hand hygiene guideline results in damaged skin and increased bacterial load. The challenge is to provide appropriate skin disinfection while maintaining an adequate and functional SC barrier. Therefore, the use of

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systems formulated to minimize the deleterious effects of repeated hand cleansing is necessary.

We hypothesized that the use of a hand hygiene regimen (ie, a ''synergistic'' set of products), referred to as the *test products* (TP), based on (1) mild (minimally disruptive) cleansers, (2) an alcohol handrub with emollient, and (3) a protective lotion would minimize the damage from hand hygiene procedures and maintain an effective SC barrier. The specific aims were as follows: (1) evaluate the effects of the synergistic regimen (TP) and the current products (CP) in health care workers (HCWs) using quantitative measures of skin condition (integrity and function) and (2) compare the changes in skin condition of HCWs using the ''synergistic'' regimen with the changes for HCWs using current products.

METHODS

Subjects: HCWs

Nurses and respiratory therapists from the Regional Center for Newborn Intensive Care (RCNIC) at Cincinnati Children's Hospital Medical Center (CCHMC) took part in the spring (n = 54) and winter (n = 61) trials. The RCNIC is a comprehensive level III intensive care unit (ICU) with approximately 190 full- and part-time staff. The ICU was selected because of the high frequency of hand hygiene procedures. Eligible subjects had (1) visible skin damage or irritation (ie, dryness, scaling, erythema) at enrollment or a verified history of damage, (2) hand hygiene frequency of at least 20 procedures per 8 hours, and (3) a schedule of at least 2 consecutive 8-hour shifts once every 2 weeks to ensure sufficient exposure to hand hygiene procedures on a regular basis. Subjects were excluded if they had a history of allergic contact dermatitis from the specific study products. The Institutional Review Board of CCHMC approved the research protocol, and all subjects provided written informed consent.

Subjects: control population

The control group (n = 26) was composed of subjects whose jobs did not involve repeated exposure to water, solvents, hand hygiene procedures, chemicals, cleaning solutions, and others. Subjects were excluded if they (1) had visible skin damage or irritation (ie, skin grades of 0.5 or higher for dryness; erythema; or fissuring at the knuckles, fingers, and dorsum), (2) had a history of skin irritation because of normal (non-HCW) handwashing, ie, 10 times in 8 hours, (3) routinely wore gloves, or (4) were outside the age range of the HCW population.

Measurement of skin condition

High-resolution digital images. High-resolution digital photographs were taken using a Fuji S2-Pro Camera 6.1 Megapixel (Fuji Corporation, Hyogo, Japan), SLR, an AF Micro-Nikkor 60mm f/2.8 Macro Lens (Nikon Corporation, Tokyo, Japan), and a Nikkon SB-29s Macro Speedlight Flash (Nikon Corporation), for a resolution of 2848 × 4256 pixels (2.8 pixels/mm). The hands were placed in a metal ''repositioning'' device to allow comparison of images from different times. Lighting conditions were controlled and standardized for white balance and color. Optical imaging methods and software (Adobe Photoshop, ImageJ; Adobe Systems, San Jose, CA) were used to evaluate and compare images for skin damage and to quantify erythema.

Expert visual grading. Separate grades were assigned to the knuckle, finger, and dorsal regions of each hand because the areas could respond differently to hand hygiene procedures. At each visit, a trained judge evaluated the skin using 0 to 5 scales for dryness and fissuring and a 0 to 4 scale for erythema. Dryness scores were as follows: 0, none; 1, patches of slight powderiness and occasional patches of small scales with generalized distribution; 2, generalized slight powderiness, early cracking or occasional small lifting scales; 3, generalized moderate powderiness and/or moderate cracking and lifting scales; 4, generalized heavy powderiness and/or heavy cracking and lifting scales; and 5, generalized high cracking and lifting scales.[29] Erythema scores: 0, none; 0.5, barely perceptible redness, weak, or spotty; 1, slight redness (spotty or diffuse); 2, moderate redness; 3, intense redness; 4, fiery redness with edema.[29] The investigators were blinded with respect to treatment (product set) at the times of visual grading, image evaluation, and instrumental data collection.

Transepidermal water loss. The SC barrier integrity was evaluated by measuring the rate of transepidermal water loss (TEWL) through the skin ($g/m^2/hr$) with a DermaLab Evaporimeter (Cortex Technology, Denmark).

Rate of transepidermal water movement. SC barrier function was assessed by measuring the rate of transepidermal moisture accumulation (MAT) during 20 seconds of continuous probe occlusion with the Corneometer (Courage and Khazaka, Koln, Germany). Water moves through the upper epidermis and builds up under the probe. The instrument measures skin hydration by determination of skin capacitance in arbitrary units (AU). MAT is the regression line slope in AU/sec.

Skin hydration. SC hydration was the first reading of the capacitance measurement (Corneometer), reported as capacitance in AU. Skin hydration is due to residual surface moisture, evaporative moisture from the dermis, and water bound to corneocyte proteins.

Subject self-assessment. HCWs completed a self-rating scale (each hand) for moisture content (dry-normal), appearance (red, blotchy, rash), intactness (abrasions, fissures), and sensation (itching, burning, stinging) on a 7-point scale, on which 0 indicated the best skin condition and 6 was the worst condition.[30]

Environmental conditions. Ambient RNCIC conditions (temperature, relative humidity) were recorded twice a day, and outdoor daily conditions were obtained from meteorologic records.

Experimental procedure

The spring trial was conducted among 2 parallel HCW groups, beginning in April 2004. The final visits were in early August 2004. One group was assigned to the test regimen (TP, liquid handwash [Kindest Kare Bodywash and Shampoo, containing amphoteric surfactants sodium lauroamphoacetate and disodium soyamphodiacetate, anionic surfactants disodium oleamido sulfosuccinate, and emollients], antimicrobial liquid handwash [CV Medicated Soap, containing Triclosan potassium; and sodium salts of fatty acids, disodium cocoamphodiacetate, and others], alcohol rub [Alcare Plus, containing ethyl alcohol, emulsifying wax, and emollients], skin lotion [Lotion Soft Skin Conditioner, containing glycerin, cyclomethicone, emulsifying wax, and emollients], STERIS Corporation, Mentor, OH) and the other group continued using the current product set (CP, liquid handwash [Endure 50, containing potassium cocoate, SD alcohol 40-B, potassium stearate, cocoamidopropyl PG-dimonium chloride phosphate], antimicrobial liquid handwash [Endure 200, containing Triclosan, potassium cocoate, propylene glycol, glycerin, potassium stearate], alcohol rub [Endure 320, containing ethyl alcohol, cetyl alcohol, PEG-32, glycerin], and skin lotion [Endure 500, containing stearic acid, glycol stearate, isopropyl palmitate, mineral oil], Ecolab Inc, St. Paul, MN). The treatment set (TP or CP) was randomly assigned to subjects at the time of their first visit (baseline measurement session) because all subjects had been using set CP prior to the start of the study. Products were supplied to all work areas. The subjects were reminded of the guidelines for hand hygiene and lotion use and used only the assigned product set throughout both trials. All subjects continued their current products and procedures for washing and skin care at home.

The winter trial took place among parallel groups from early December 2004 through early March 2005. Most subjects took part in both trials, and the initial CP or TP product assignment was maintained so that the effect of season could be determined effectively, ie, same product in both seasons. During the time between trials, all HCWs returned to using CP for hand hygiene procedures. Subjects were enrolled in the winter trial, assigned to use the same product set as they had in the spring, and instructed to use the product prior to the first visit of cycle 1 to ensure that the observed skin effects were attributable to product exposure. The subjects had been using the assigned products for at least 6 days (mean 21 days; range, 6-34 days) prior to the first measurement visit, ie, after transition to the new product. Subjects who were new to the research were randomly assigned to CP or TP at the start of the winter study.

The HCWs typically work 12-hour shifts. Full-time personnel generally work 3 consecutive days with 3 or 4 days between cycles. Part-time personnel had to work at least 2 consecutive shifts on a regular basis to participate. The effects of the hand hygiene procedures and products were determined by measuring the skin condition during a set of shifts, ie, from beginning (prior to the initial scrub) to end (approximately an hour after the last procedure) of a work cycle. The start and end visits together constituted a cycle. The skin was evaluated for 6 cycles (12 visits) during spring and 3 cycles during winter, with visits arranged in accordance with subject schedules. In the winter trial, subjects were evaluated again when they returned to work following their time off after cycle 3 (visit 7).

A volar forearm site outside the treatment area (between elbow crease and wrist) was evaluated as a within-subject control. This site was not an ideal control because of variations in product exposure and skin characteristics (hand vs forearm). However, repeated evaluation of a relatively unperturbed site provided information on the variability in skin condition. To avoid measurement order bias, the hands were randomized, eg, assessments began with left or right hand. The forearm was the same side as the starting hand (ie, left hand first, left forearm).

The evaluations were performed in a designated area within the RCNIC. The subjects first completed the self-assessment of each hand. The sequence began with the control hand (left or right) as follows: control hand image, visual grading (knuckles, fingers, dorsum), other hand image, visual grading, hydration (dorsum, forearm, other dorsum), and TEWL (dorsum, forearm, other dorsum). The hydration and TEWL readings were made on adjacent sites to avoid carryover effects of the instrumental procedures. The order of evaluations was maintained at each visit. The control subjects (non-HCWs) were assessed once in late June-early July of 2005 for grades, imaging, hydration, and TEWL.

Statistical analysis

The data were analyzed with Sigma Stat Software (SPSS, Inc., Chicago, IL) and a significance level of $P \leq .05$. Results are reported as mean $\pm$ SD and mean $\pm$ SEM. Paired t test procedures were used to compare the skin condition at the beginning and end of each work cycle and the skin condition for spring versus

Table 1. Health care worker demographic characteristics*

	Spring		Winter	
Characteristic	**Current product**	**Test product**	**Current product**	**Test product**
Number of subjects	25	29	31	30
Sex				
Female	25	29	30	30
Male	–	–	1	–
Race				
White	23	26	30	29
Black	2	3	1	1
Total mean study duration (day)	49.7 ± 12.0	58.3 ± 13.4	34.9 ± 12.2	34.9 ± 8.8
Mean cycle duration (day)				
Cycle 1	2.6 ± 1.2	2.1 ± 0.8	2.5 ± 1.2	2.2 ± 0.8
Cycle 2	2.5 ± 1.0	2.7 ± 1.1	2.5 ± 1.1	2.4 ± 1.0
Cycle 3	2.9 ± 1.2	2.7 ± 1.2	2.6 ± 1.2	2.6 ± 1.8
Cycle 4	2.7 ± 1.4	2.7 ± 1.2	–	–
Cycle 5	2.8 ± 1.1	2.3 ± 1.6	–	–
Cycle 6	3.0 ± 2.5	2.5 ± 0.9	–	–

*Values are presented as mean ± SD.

Table 2. Environmental conditions*

Mean dew point (°C)	Spring	Winter
Outdoor conditions	16.3°C ± 4.5°C	−2.6°C ± 7.4°C
Indoor conditions (RCNIC)	6.1°C ± 1.5°C	2.3°C ± 2.3°C

*Values are presented as mean ± SD.

winter (among the subjects who did both studies). Regional differences in skin condition (eg, dryness, erythema) were assessed by analysis of variance. Student *t* tests were used to compare the skin condition of the CP and TP groups at various time points. The effects of the treatment (CP set vs. TP set) were determined by computing the change in skin condition as final (end of cycle) minus start (beginning of cycle) and using Student *t* tests to compare the changes for CP versus TP.

RESULTS

Fifty-six HCWs participated in the spring trial, and 60 were in the winter study. Twenty-three CP and 25 TP subjects took part in both trials. The demographics and the number of days of product exposure (ie, length of cycle) are shown in Table 1. The cycle times for CP and TP subjects were not significantly different for any of the 6 spring cycles or the 3 winter cycles, indicating that product comparisons are valid.

The outdoor dew points were significantly different between the seasons, averaging 16.3°C ± 4.5°C for spring and −2.6°C ± 7.4°C for winter. The indoor RCNIC unit dew points were significantly different as well, with 6.1°C ± 1.5°C in spring and 2.3°C ± 2.3°C in winter (Table 2). Unit dew points in the spring were substantially lower than outdoor conditions. These relatively dry ambient work conditions contributed to the stress on skin from hand hygiene procedures. No significant differences were observed in either outdoor or unit dew points for CP compared with TP at any cycle during spring and winter. The outdoor dew point was significantly higher for spring cycle 5 compared with cycle 2 (ANOVA, $P < .05$). This finding indicates an increase in dew point during the study, as expected from the historical weather conditions. The dew points did not vary significantly throughout the winter cycles.

Comparison with non-HCW control subjects

The skin condition at the start of a cycle (cycle 6, spring) was compared with that of the non-HCW controls. Visual dryness/scaling and erythema scores in all regions (knuckle, finger, and dorsum) were significantly higher for the HCWs (Table 3). This finding is not surprising, given that the basis for selection for controls was the lack of visible dryness and erythema. However, it verifies the increased skin damage experienced by HCWs. Skin hydration (knuckle, dorsum, and forearm sites) was significantly lower for the HCWs than for the control subjects, indicating drier skin. For the non-HCW controls, TEWL values were significantly higher on the dorsum (10.0 ± 1.6 g/m^2/hr) than the volar forearm (7.2 ± 1.2 g/m^2/hr) because of, at least in part, to structural and physiologic differences between sites. TEWL (dorsum and forearm) was significantly higher for the HCWs than for the control group, indicating a poorer SC barrier.

Table 3. Skin condition of HCWs versus control subjects*

Attribute	HCW (n = 24)	Control (Non-HCW) (n = 26)	*t* Test *P* value
Visual dryness/scaling score			
Knuckle	0.73 ± 0.14	0.00	<.001
Fingers	1.1 ± 0.12	0.00	<.001
Dorsum	0.67 ± 0.11	0.00	<.001
Visual erythema score			
Knuckles	1.3 ± 0.11	0.00	<.001
Fingers	0.79 ± 0.07	0.00	<.001
Dorsum	0.85 ± 0.08	0.00	<.001
Skin hydration (baseline, AU)			
Knuckle	26.4 ± 1.6	38.2 ± 1.8	<.001
Dorsum	38.7 ± 2.1	52.4 ± 2.1	<.001
Forearm	37.2 ± 2.1	58.8 ± 1.9	<.001
Transepidermal Water Loss ($g/m^2/hr$)			
Dorsum	13.6 ± 1.7	8.1 ± 0.48	<.001
Forearm	7.0 ± 0.4	5.6 ± 0.37	.01

*Values are presented as mean ± SEM.

Initial skin condition: HCWs

At the start of the spring trial, all subjects (n = 54) had been using the CP. Significant regional differences ($P < .001$, ANOVA) were found in visual dryness in the order: finger > knuckle > dorsum (Fig 1A). The right hand regions were significantly drier than the left. All HCWs were right handed with one exception. Significant regional differences were observed for erythema (knuckle > finger > dorsum), with the knuckle having the highest score (most damage) (Fig 1B). The mean self-assessment scores (0-6 scale, on which 0 is best and 6 is worst) at baseline for the right hand were as follows: appearance = 1.8 ± 0.2, intactness = 1.6 ± 0.2, moisture content = 3.2 ± 0.2, and sensation = 2.0 ± 0.2, indicating that the HCWs perceived their skin to be compromised at the start of a work cycle. The left and right hands were not different by self-assessment. Significant regional differences in skin condition were also found at the beginning of the winter trial. The visual dryness scores for the knuckle and finger were significantly higher than for the dorsum (Fig 2A). Baseline hydration measurements revealed no significant differences among the left dorsum, right dorsum, and volar forearm sites (ANOVA). The moisture accumulation rate was significantly higher for the left dorsum (0.54 ± 0.04 AU/s) compared with the volar forearm (0.36 ± 0.03 AU/s) (ANOVA). Baseline TEWL values indicated significant differences between the dorsal and volar forearm sites, with mean values of 12.0 ± 0.9 $g/m^2/hr$ for the left dorsum, 12.3 ± 0.7 $g/m^2/hr$ for the right dorsum, and 6.4 ± 0.5 $g/m^2/hr$ for the forearm. The nearly 2-fold difference between

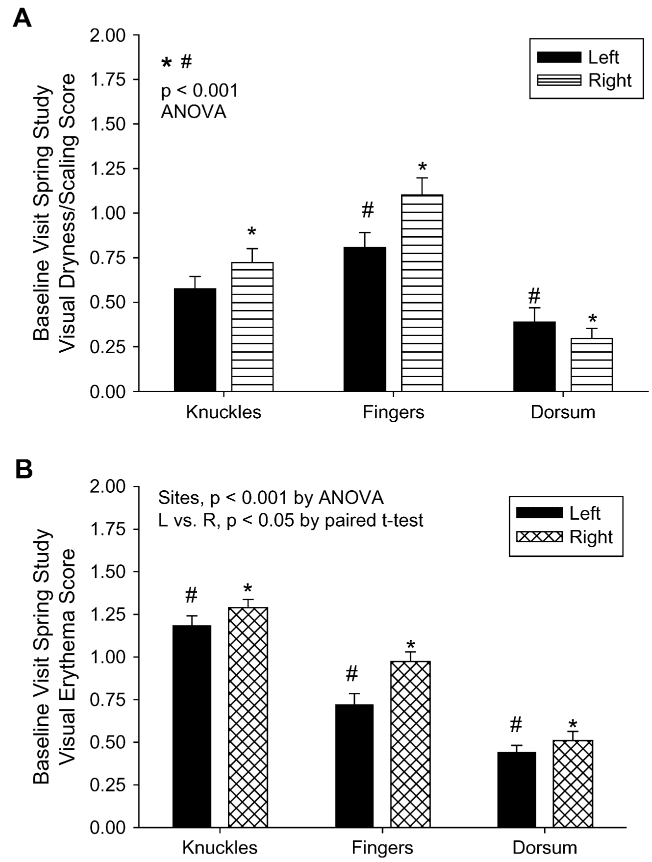

Fig 1. Initial skin condition-HCWs. At the start of the spring trial, significant regional differences ($P < .001$, ANOVA) in visual dryness (n = 54) were observed in the following order: finger > knuckle > dorsum (**A**). The right hand regions were significantly drier (higher score) than the left. Skin erythema (n = 54) was significantly different across the hand (knuckle > finger > dorsum) with the highest score (most damage) for the knuckle (**B**).

dorsum and forearm is attributed in part to structural and physiologic differences in these regions and due not only to differences in SC barrier function.

For the spring trial, subjects were randomly assigned to treatment CP or TP. The skin condition for the 2 groups at baseline (prior to any hand hygiene procedures) was compared (*t* tests). No significant differences were observed, indicating that the 2 groups were balanced for starting skin condition. The initial dryness grades (mean ± SEM) for CP and TP, respectively, were as follows: left knuckle (0.6 ± 0.1 vs 0.5 ± 0.1), right knuckle (0.7 ± 0.1, both), left finger (0.8 ± 0.1, both), right finger (1.0 ± 0.1 vs 1.2 ± 0.2), left dorsum (0.4 ± 0.1, both), and right dorsum (0.3 ± 0.1, both). The initial erythema scores for CP and TP, respectively, were as follows: left knuckle (1.2 ± 0.1, both), right knuckle

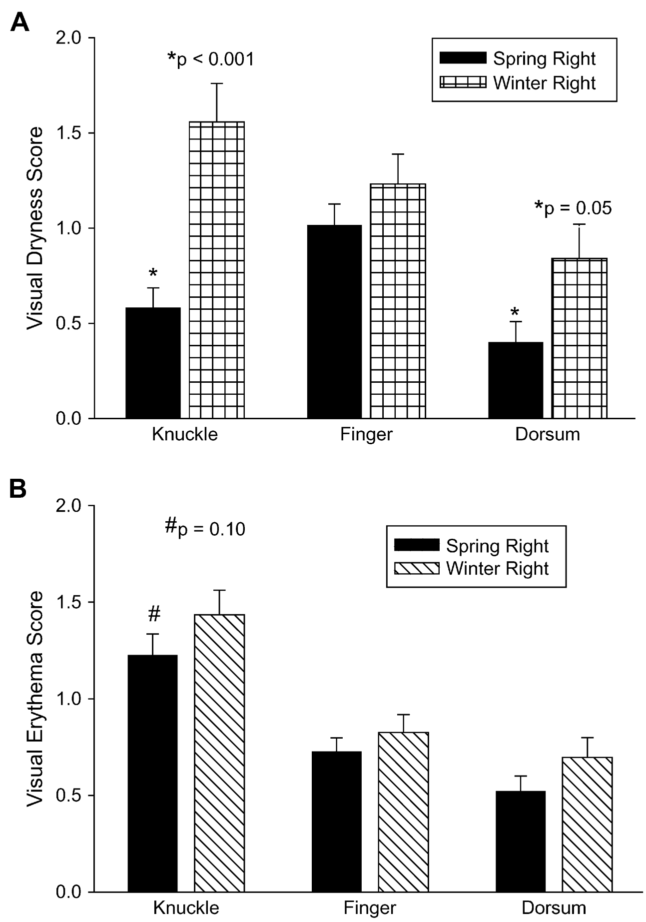

Fig 2. Effect of season on skin condition. The effect of season was determined in the HCWs who used the current products (CP) in both trials (n = 23). Spring (third cycle, visit 5) and winter (third cycle, visit 5) measurements were analyzed using paired *t* tests. Dryness grades were significantly higher during the winter for the knuckles ($P < .001$) and dorsum ($P = .05$) regions (**A**; right hand), indicating poorer skin condition. Visual erythema scores were comparable between the seasons for the finger and dorsum areas and directionally higher ($P = .10$, poorer skin condition) during the winter for the knuckles (**B**).

(1.3 ± 0.1 both), left finger (0.8 ± 0.1 vs 0.7 ± 0.1), right finger (1.0 ± 0.1 vs 0.9 ± 0.1), left dorsum (0.5 ± 0.05 vs 0.4 ± 0.1), and right dorsum (0.5 ± 0.1, both).

For the winter trial, subjects began using their assigned (ie, for spring) treatments in advance of the first measurement session to ensure that the starting skin condition was influenced by specific product usage. The exposure time averaged 21 days (range, 6-34 days) prior to the first evaluation (day 1 of cycle 1). Comparison of this "initial" skin condition for groups CP versus TP (*t* tests) indicated a significant difference ($P < .05$) for the left dorsum erythema grade (0.8 ± 0.1 for CP vs 0.4 ± 0.1 for TP). The dryness grades at the official start of the winter study for CP and TP, respectively, were as follows: left knuckle (1.0 ± 0.1 vs 1.2 ± 0.1), right knuckle (0.1.2 ± 0.2 vs 1.2 ± 0.1), left finger (1.0 ± 0.1 vs 1.2 ± 0.1), right finger (1.2 ± 0.1 vs 1.5 ± 0.1), left dorsum (0.3 ± 0.1 vs 0.6 ± 0.1), and right dorsum (0.6 ± 0.1 vs. 0.7 ± 0.1). The initial erythema scores for CP and TP, respectively, were as follows: left knuckle (1.2 ± 0.1 vs 1.4 ± 0.1), right knuckle (1.4 ± 0.1 vs 1.3 ± 0.1), left finger (0.8 ± 0.1 vs 0.6 ± 0.1), right finger (0.8 ± 0.1 both), left dorsum (0.8 ± 0.1 vs 0.4 ± 0.1), and right dorsum (0.7 ± 0.1 vs 0.5 ± 0.1).

Effect of season on skin condition

The effect of season (outside environmental conditions) was determined by examining the skin condition of the HCWs who participated in both trials. They had used the CP prior to the studies, throughout both trials, and during interim periods. Measurements from spring (third cycle, visit 5) and winter (third cycle, visit 5) were compared using paired *t* tests. Dryness grades were significantly higher during the winter for the knuckles ($P < .001$) and dorsum ($P = .05$) regions (Fig 2A, right hand), indicating poorer skin condition during winter. Visual erythema scores were comparable for winter and spring on the fingers and dorsum and directionally higher ($P = .10$) in winter for the knuckles (Fig 2B). Significant differences between seasons were also observed in the HCW self-assessment scores. Instrumental skin hydration values were not different for spring visit 5 and winter visit 5.

The self-assessment ratings were significantly higher during winter. Scores from the late spring (visit 9, n = 23) were compared with the first winter visit (*t* tests, n = 30). Mean scores were (right hand) as follows: intactness (0.61 ± 0.2 spring vs 1.6 ± 0.2 winter), moisture content (1.3 ± 0.2 spring vs 2.6 ± 0.3 winter), and sensation (0.5 ± 0.2 spring vs 1.4 ± 0.2 winter). Appearance ratings were directionally different (0.9 ± 0.2 vs 1.6 ± 0.2, $P = .06$). The HCWs judged their skin to be in poorer condition in winter than in spring.

Effect of hand hygiene procedures on skin integrity

The effects of repetitive hand hygiene procedures on HCW skin condition were determined by comparing the measurements at the end of a cycle with those at the start, ie, upon return to work after time off (paired *t* tests). In general for treatment CP, the skin was in poorer condition (higher grades) at the end of a cycle than at the start during both the spring and winter trials. For the test treatment (TP), the visual scores, particularly those for dryness/scaling, were often lower at the end of the cycle compared with the start, suggesting that the skin condition improved. During the winter study, dryness tended to decrease (improve) and erythema increased for subjects on TP. For some cycles, the skin worsened for the CP and remained unchanged for TP. For others, the skin was unchanged with CP and improved with use of TP.

Similarly, significant changes were observed for the HCW self-assessment parameters over the work cycles. Higher values indicate poorer skin condition For spring cycle 1, intactness and moisture content had lower scores (better condition) at the end of the cycle than at the start for TP and were unchanged for CP. For other attributes and cycles, the skin was generally considered to be in poorer condition at the end of a cycle than at the start. However, the number of significant increases (worsening) was greater for CP than for TP during both seasons. For example, in winter cycle 2, the skin was rated as significantly poorer for sensation and moisture content for CP but remained unchanged for TP.

Effect of treatments CP versus TP

The most direct comparison of specific treatment effects could be made by comparing the changes in skin condition (dryness, erythema, hydration, and others) during a cycle for the HCWs on TP with those on CP. The cycles for the 2 groups occurred simultaneously, and a comparison of changes in the skin measurements served to minimize the impact of differences in environmental conditions. The changes were computed as final (end of cycle) minus initial (start of cycle). The changes for CP were compared with the changes for TP with Student *t* tests. Using this comparison, treatments CP and TP were significantly different for various skin measures during the spring and winter trials. Figure 3A to 3D shows the changes for CP versus TP for visual skin dryness at the dorsum and knuckle sites in the spring and winter. Positive changes indicate worsening of the skin condition (increase in grade), and negative changes indicate improvement. In general, the condition worsened (dryness increased) or remained unchanged for CP throughout both seasons. For TP, the condition either improved (dryness decreased), was unchanged, or increased to a lesser extent than CP (Fig 3A-D) The differences were significant ($P <$ .05) for spring cycles 1 and 3 and for winter cycles 1 and 2. They were directionally different for spring cycle 4. A similar pattern occurred for knuckle dryness, although the differences were significant for spring cycles 1 and 2. The changes were directionally different ($P =$ .06) for finger dryness in winter cycle 1, wherein the CP group experienced an increase relative to the decrease for TP.

Changes in dorsal skin hydration (capacitance-based instrumental methods) for CP versus TP during spring and winter cycles revealed consistent findings (Fig 4). For spring cycles 1 and 4, the treatments were significantly different with an increase in hydration for TP and a decrease for CP. For cycle 1, the change in hydration was 5.2 $\pm$ 2.2 AUs for TP, and -5.6 ± 2.8 AUs for CP. An increase in hydration is associated with improved skin condition. Importantly, adequate skin hydration is necessary for restoration of SC barrier function. Treatment TP consistently resulted in higher skin hydration compared with CP, as shown in Figure 4.

Comparisons of the changes in HCW self-assessment over a work cycle for CP versus TP also revealed significant differences in treatments. Figure 5A and 5B show the changes in the self-assessment of moisture content for CP and TP during spring and winter. A positive change (end-start) indicates poorer skin condition at the end of the work cycle. The change in moisture content was significantly different for CP versus TP for spring cycles 2 and 6 (cycle 2 changes of 0.1 $\pm$ 0.2 for TP and 0.84 $\pm$ 0.3 for CP, cycle 6 changes of -0.10 ± 0.1 for TP and 0.59 $\pm$ 0.2 for CP). During spring cycle 4, the changes in appearance and intactness were significantly greater CP than for TP (intactness change of -0.11 ± 0.1 for TP and 0.38 $\pm$ 0.1 for CP and appearance change of 0 $\pm$ 0.1 for TP and 0.46 $\pm$ 0.1 for CP). These findings indicate that the skin was perceived to be in poorer condition at the end of the cycle for CP versus TP.

Effects of treatments CP and TP over time

The impact of the 2 hand hygiene treatments over the duration of each trial was determined by comparing the changes in skin condition (visual grades, hydration, self-assessment) for CP versus TP. For the spring study, the change in each parameter was calculated for visit 11 (start of cycle 6) versus visit 1. The change for CP was compared with the change for TP (*t* tests). Although the differences were not statistically significant ($P <$ .05), the decrease in right knuckle dryness of -0.3 ± 0.1 for TP was different from the change of 0.0 $\pm$ 0.1 for CP (confidence level of $P =$ .11). Given the standard error of the measurement, a sample size of 50 subjects per test group would be required to demonstrate a statistically significant difference ($P <$ .05). For the winter study, the change in each measurement was calculated for visit 7 (return to work day following cycle 3) versus visit 1 (subjects had been using assigned products for a mean of 21 days). Although the differences were not statistically significant, the change in left dorsum dryness of 0.4 $\pm$ 0.2 for CP was different from the change of -0.1 ± 0.2 for TP (confidence level of $P =$ .09). With the observed standard error, a sample

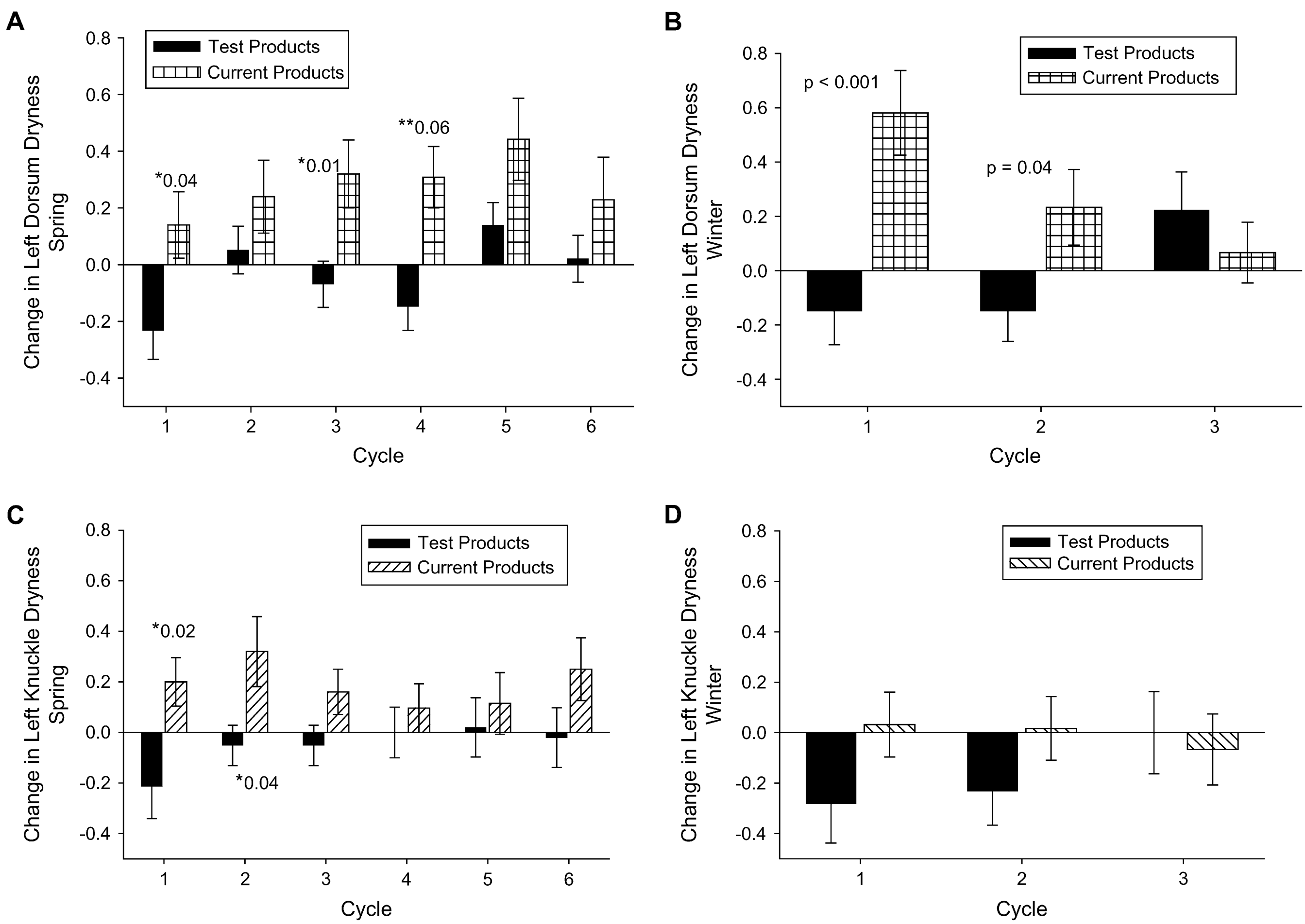

Fig 3. Effect of treatments: current products (CP) versus test products (TP). A to D shows the changes for CP versus TP for visual skin dryness at the dorsum and knuckle sites in the spring (n = 26, CP; n = 29, TP) and winter (n = 31, CP; n = 30, TP). Positive changes indicate worsening of the skin condition, and negative changes indicate improvement. In general, the condition worsened or remained unchanged for CP throughout both seasons. For TP, the condition either improved, was unchanged, or increased to a lesser extent than CP. The differences were significant ($P < .05$) for spring cycles 1 and 3 and for winter cycles 1 and 2 and directionally different for spring cycle 4. A similar pattern occurred for knuckle dryness, although the differences were significant for spring cycles 1 and 2. The changes were directionally different ($P = .06$) for finger dryness in winter cycle 1, wherein the CP group experienced an increase relative to the decrease for TP.

size of approximately 70 subjects per group would be required for statistical significance at $P < .05$.

DISCUSSION

In this research, we demonstrated that specific hand hygiene product sets, ie, the CP and the "synergistic regimen" TP, vary significantly in their effects on the SC barrier under 2 different sets of environmental conditions. Use of the TP resulted in significantly improved skin condition relative to the CP at times during the spring and winter trials. We used 3 clinical measurements to investigate the effects of the hand hygiene processes and product sets: visual skin evaluation (dryness, erythema), instrumental assessment of SC barrier integrity and function (skin hydration, TEWL), and HCW self-assessment of skin condition (moisture content, intactness, appearance, sensation). The comparative data show significant differences between CP and TP in at least 1 measure for cycles 1, 2, 3, 4, and 6 of the spring trial and cycles 1 and 2 of the winter trial and collectively indicate differences between the 2 treatments. Importantly, all 3 methods indicate that the use of TP results in increased skin hydration and suggest that TP help maintain/restore hydration relative to products CP and under the same conditions of use (eg, days on treatment, environmental conditions, initial skin condition).

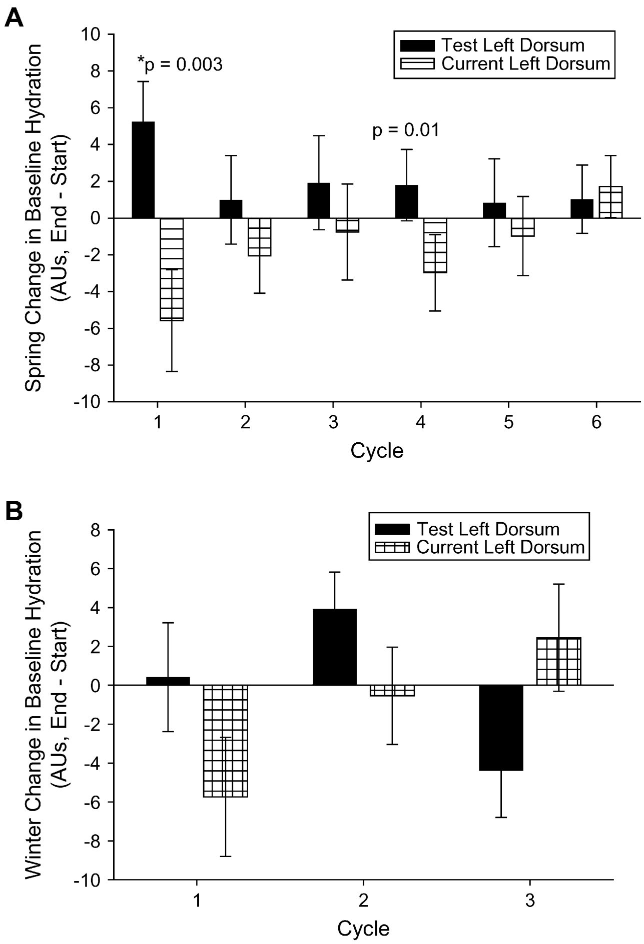

Fig 4. Effect of treatments on skin hydration. **A** and **B** shows the changes for CP versus TP for skin hydration at the left dorsum in the spring and winter. Positive changes indicate an improvement in the skin condition (higher values indicate greater moisture). For spring cycle 1, the treatments were significantly different for changes in skin hydration.

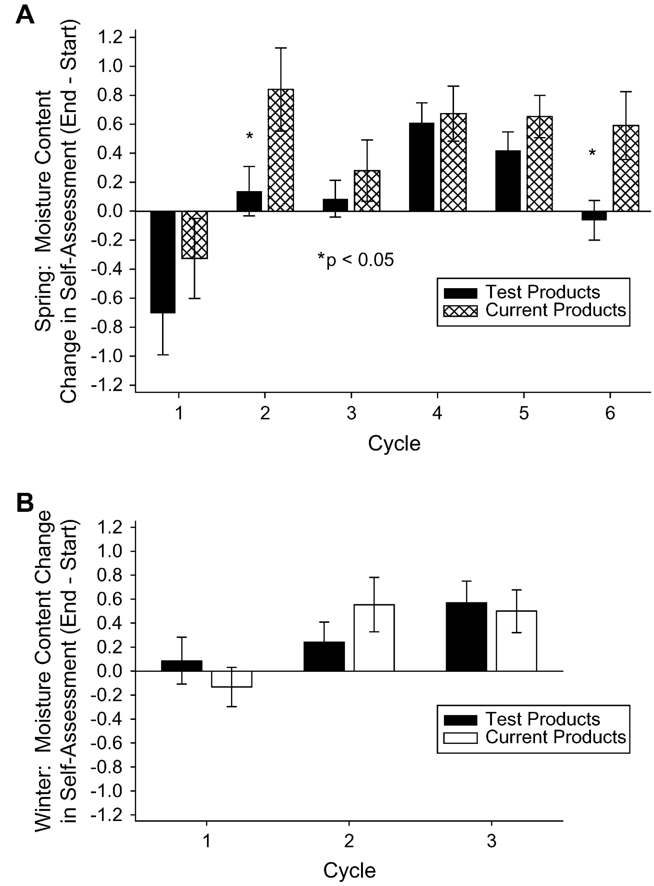

Fig 5. Effect of treatments on subject self-assessment of moisture content. **A** and **B** shows the changes for CP versus TP for subject self-assessment of hand moisture content for spring and summer. A positive change (end-start) indicates poorer skin condition at the end of the work cycle. The change in moisture content was significantly different for CP versus TP for spring cycles 2 and 6.

Prior to the start of the spring trial, the majority of HCWs had discontinued using the CP antimicrobial liquid handwash (Endure 200) because of incidences of significant irritant dermatitis among some of the RCNIC staff and the general awareness of the product's irritancy. As a consequence, most of the HCWs assigned to CP used only the nonantimicrobial handwash and greatly limited the use of the CP antimicrobial version during the research. Overall, the hand skin of HCWs who work consecutive shifts is appreciably compromised, as evidenced by dryness/scaling, persistent erythema, self-assessment, and measures of hydration. The skin was compromised at the start of a cycle for the majority of HCWs, indicating that hand hygiene procedures result in significant SC barrier damage that does not appear to recover during time away from work. Under normal conditions, the SC turnover time is 14 days, ie, for cells to move from the bottom of the SC to the top where desquamation occurs. Fourteen days are required for repair of SC damage. The time between work cycles is, therefore, insufficient for full repair. This result further emphasizes the importance of providing skin care products to minimize irritant dermatitis.[5] Statistically significant differences between CP and TP were not observed over the course of either trial. However, the subjects continued to use their typical skin care products at home and during time away from work. These products were not consistent across the total HCW subject population, however. The effects on skin of hand hygiene with CP and TP over time could be accurately determined by having subjects use the assigned products at all times, thereby reducing confounding product and usage effects.

Reports in the literature discuss the impact of repetitive hand cleansing/disinfection procedures on skin condition.[20,31-35] To elucidate the mechanisms underlying the effects of product exposure, researchers use methods that model repetitive exposure, often using the volar forearm as a test site.[18,22,34,36] Relatively few accounts investigate various aspects of hand skin condition among health care workers in realistic clinical settings.[30,37-42] Our report is the first to examine the effects on hand skin condition of 2 different product regimens among HCWs in an actual clinical setting and in 2 seasons.

The hand skin condition was significantly worse during the low-dew-point winter conditions, as evidenced by significantly higher visual dryness/scaling and self-assessment of intactness, moisture content, and sensation among subjects who used the current products over both seasons. The effects of decreased external environmental conditions (ie, dew point, defined as the temperature at which dew forms and a measure of atmospheric moisture content) on skin condition have been described.[43-46] The increased dryness/scaling and reduced hydration has been attributed to decreases in the production of the water-binding natural moisturizing factor (NMF) in the outer SC.[45] Additionally, reduction in the SC barrier lipids (particularly ceramide 1-linoleate) has been found in vivo during low humidity (low dew point) conditions.[46] SC damage from surfactant exposure was greater in the winter compared with the summer for some surfactants (ie, sodium lauryl sulfate; SLS) but not for others.[43] Our results are consistent with those of Larson et al, who found the use of a mild cleanser or alcohol rub plus lotion to be better after 4 weeks of use when compared with a surgical scrub plus lotion (scheduled application).[39] The skin condition of nurses in a cold climate (Wisconsin) was compared with that of nurses in a warmer locale (Arizona) in winter and summer.[42] Winter and summer visual dryness scores were significantly higher for nurses in Wisconsin. For both groups, the erythema, scaling, and cracking grades indicated that skin condition was poorer in the winter. The researchers found that high handwashing frequency and subject age contributed to poorer skin condition. The present study did not investigate the effect of the number of hand hygiene procedures per shift because all HCWs worked in an intensive care unit and they could not be differentiated on the basis of frequency.

Skin erythema was difficult to assess, most likely because of the extent of compromise and the regional heterogeneity. The knuckles were generally higher in erythema than the fingers or the dorsal surfaces. The severity, ie, degree or amount of erythema, was particularly problematic because it was difficult to differentiate levels (ie, slight, mild, moderate, severe). Inherently, skin tone has a red component, and it was difficult to separate (subtract) the inherent erythema with that caused by the hand hygiene procedures. Additionally, the hands at the start and the end of cycle were graded at different times (2 or 3 days apart). Figure 6 shows high-resolution digital images for an example subject. The image resolution is sufficiently high to permit specific regions of interest to be magnified and viewed in detail on a high-resolution monitor. Region 1 shows the knuckle and web regions near the dorsum. Dryness, scaling, and erythema are visible for quantitation. Region 2 shows the dryness and scaling observed on the knuckles. To address the limitations of the visual grading methods, we have begun to apply image analysis techniques to the digital photographs to quantify erythema. We are currently using a visual perception system for simultaneous comparison of images, ie, beginning versus end of a work cycle. These methods allow the comparison of the same subject in spring versus winter and from one part of the season to another. Scoring will be conducted by the expert graders and groups of HCWs. These evaluations are underway and will be reported in the future. The HCWs in this research used the same product set, ie, CP or TP, for both trials. A comparison of products CP versus TP on the total population in one season (eg, a crossover comparison) is also of interest, particularly because the variables associated with the subject populations would be minimized. Because treatment effects can be determined in 3 cycles, further evaluations of CP versus TP within the winter season should be done to generate the appropriate data for paired-comparison assessment of treatment effects.

The instrumental measurements indicated that the skin hydration of the HCWs was generally lower than that for the non-HCW control group. Additionally, the unit conditions were relatively dry (dew points of 6.1°C ± 1.5°C for spring and 2.3°C ± 2.3°C for winter), contributing to the relatively low skin hydration. The capacitance-based instruments used in this research were designed to measure somewhat higher levels of hydration and may lack the capacity to accurately differentiate states of low hydration. Future studies should explore the use of dynamic measures of skin hydration, such as the water sorption-desorption profile.[47]

During the 2 trials, the impracticality for subjects to maintain the necessary resting state for TEWL measurements (20 minutes prior to measurement) resulted in high standard deviations. TEWL is also affected by unit dew point conditions, and differences between spring and summer could be due to factors other

Fig 6. High-resolution digital photographs. The Fig provides an example of the high-resolution digital photographs. The whole hand is viewed on a high-resolution computer monitor. The image resolution is sufficiently high to permit specific regions of interest to be magnified and viewed in detail. Region 1 shows the knuckle and web regions near the dorsum. Dryness, scaling, and erythema are visible for quantitation. Region 2 shows the dryness and scaling observed on the knuckles.

than inherent skin condition. Therefore, we do not consider this measure to be reliable and informative.

Investigations by Sato et al[14] provide insight into the biologic mechanisms underlying the observed effects of hand hygiene practices on measures of SC barrier integrity. Mice were kept in a humid environment and then transferred to a very dry environment. Evaluations showed a rapid decrease in SC hydration, compromise in barrier homeostasis, and decreased epidermal proliferation. The humidity change resulted in decreased lamellar body secretion, which, in turn, led to a decrease in the SC lipid bilayers and disruption in barrier function. The authors speculated that abrupt changes in humidity might be quite stressful in situations where SC barrier compromise already exists. We found that HCWs had a lower SC hydration than non-HCW controls and that the skin was dry at the start of a work cycle. HCWs experience dry to humid to dry cycles repeatedly throughout their shifts. Denda's model simulates part of the HCW cycle, ie, high humidity during soap and water washing followed by the rapid decrease in humidity (towel drying) and exposure to the relatively dry unit environment. The findings of increased skin hydration for TP suggest that the abrupt changes in skin hydration (because of repeated hydration and drying) may be mitigated to a greater extent for TP than for CP. The maintenance of appropriate hydration is an important mechanism for skin integrity.

The effects of skin cleansing surfactants on skin irritation and SC barrier integrity have been rather extensively addressed. Most of the research is conducted on other body sites and/or using controlled application (occlusive patch) protocols, rather than in actual clinical use. Although surfactants alone can be classified regarding "irritancy potential," their effects in full products are influenced by a number of factors, including quantity, rinseability, protein-binding affinity, and interactions with SC lipids.[48] Therefore, the overall formula irritancy potential is very difficult to determine from product ingredient listing alone. The effects of individual hand hygiene products within the set have been studied. An emulsion cleanser and a liquid soap were compared among parallel groups of HCWs with histories of skin problems.[41] The emulsion cleanser resulted in reduced skin dryness, whereas the liquid soap caused significant increases in dryness.[41] Another report compared a liquid soap to an alcohol handrinse among nurses for 8 days.[28] The alcohol handrinse resulted in signficantly better decontamination of the skin surface (total counts of colony-forming units as an index of bacterial kill), and the skin dryness and redness worsened signifciantly for the soap group. A 2% chlorhexidine gluconate washing product was compared with a waterless alcohol rub with emollients among 2 parallel groups (n = 25) of nurses for 4 weeks.[40] Both groups were provided with skin lotion for use after handcleansing with either the washing product or the waterless alcohol rub. The alcohol rub treatment resulted in significantly better skin condition than the washing product.

The positive effects of lotion on skin condition among workers engaged in repetitive exposure to water and surfactants have been described.[49] Use of lotion resulted in improvements in clinical grades and instrumental hydration. No differences in TEWL were observed, consistent with our findings. Loden demonstrated that application of moisturizer resulted in more rapid SC barrier repair following damage with surfactant (sodium lauryl sulfate) compared with a no lotion control.[50] The efficacy of 2 lotion types in workers with severe hand irritation (n = 54) was evaluated over 4 weeks.[51] The oil-based lotion (mineral oil, petrolatum, lanolin, and others) resulted in signficantly better skin scores than the glycerin-based lotion (glycerin, isopropyl myristate, stearic acid, and others). However, the oil-based lotion cannot be used with gloves because the integrity can be compromised, a feature that must be considered in the selection of products for HCWs.

Our investigations demonstrate that product composition and selection can significantly influence HCW skin condition. An investigation of the relationship between skin damage and bacteria counts found total counts to be higher as skin damage increased.[28] Damaged skin was found to have higher levels of colonizing microbial flora.[52] Therefore, regimens that are designed to minimize the damaging effects of hand hygiene practices can improve skin condition while achieving skin disinfection. Importantly, the use of such products is expected to substantially impact and increase hand hygiene compliance. HCWs should be encouraged to use alcohol sanitizers with emollients whenever possible to avoid negative effects of exposure to surfactant and water. Equally important are the use of lotions at work and protective skin care practices (mild cleansers, lotions, avoidance of harsh chemicals) during time away from the workplace.

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