

ORIGINAL ARTICLE

Skin barrier function in nursing apprentices during the coronavirus disease 2019 (COVID-19) pandemic

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Abstract

Background: Studies investigating simultaneous influence of personal and work-related factors on skin health during the coronavirus disease 2019 (COVID-19) pandemic are missing.

Objectives: To investigate the associations of skin hazards relevant for nursing apprentices with parameters of skin barrier function.

Methods: A total of 238 nursing apprentices attending the final year of education (median age 19 years) from vocational schools in Zagreb, Croatia, were enrolled in this study. We administered a questionnaire based on the Nordic Occupational Skin Questionnaire to the nursing apprentices, performed clinical examination of skin on the hands, and evaluated transepidermal water loss (TEWL) and stratum corneum (SC) pH on the dorsum of the hand.

Results: Around half of nursing apprentices had compromised hand skin barrier function, as indicated by TEWL values $>25 \text{ g/m}^2/\text{h}$ (48%) and SC pH >5.5 (57%). Skin barrier was compromised in around 40% of nursing apprentices without clinically observed skin symptoms. Elevated SC pH was independent of ambient conditions associated with skin symptoms and female sex.

Conclusions: Measurement of SC pH was shown to be less sensitive to field conditions than TEWL, and should be employed more in the field studies. Strengthening of skin health promotion in healthcare workers and apprentices is needed in pandemic conditions.

KEYWORDS

COVID-19, nursing, nursing apprentices, pH, skin barrier, TEWL

1 | INTRODUCTION

Measurement of transepidermal water loss (TEWL) and stratum corneum (SC) pH provides objective information on the skin. Increased TEWL and pH above physiological levels indicate compromised SC integrity or function. Significantly higher hand TEWL values were found among nurses in comparison to workers not exposed to skin hazards.^{1,2} Furthermore, a significant increase in hand TEWL among nursing apprentices was seen after just 10 weeks of regular practical training.³ Despite this, there are studies questioning the use of TEWL measurement among nursing apprentices as a predictor of development of skin symptoms.⁴ Because of the coronavirus disease 2019

(COVID-19) pandemic, there is increased strain on the skin, particularly among healthcare workers, due to the intense hand hygiene requirement (eg, longer hand washing durations, washing the hands more often, prolonged glove use). Frequent hand washing and skin occlusion under prolonged glove use seem to have a profound negative impact on skin barrier function noted by increases in TEWL values.^{4,5} In addition, occlusion significantly enhances the skin barrier damage caused by soaps in a dose-response manner.⁶ By contrast, hand sanitizers on their own do not seem to disturb TEWL,⁴ but they alter the SC pH.⁷ However, hand sanitizers can worsen existing skin irritation because a significant increase in TEWL values was noted when *n*-propanol was applied in concentrations commonly used in

sanitizers on skin previously irritated by detergents.⁸ When investigating associations of work-related exposure, personal factors should also be included in an analysis, because studies have shown significant associations of age, sex, and atopic status with parameters of skin barrier function.^{9,10} Overall, there is a need for more studies investigating the simultaneous influence of several personal and work-related factors in a real-life setting of increased hand hygiene regimen, especially during the COVID-19 pandemic, because the recent prevalence of hand dermatitis among healthcare workers was reported to be around 75%¹¹ and around 50% among nursing apprentices.¹²

To address this need, the aim of our study was to investigate the associations of skin hazards relevant for healthcare workers including frequent hand washing, hand sanitizing, and prolonged glove use with parameters of skin barrier function among nursing apprentices attending the final year of their education during the COVID-19 pandemic.

2 | PARTICIPANTS AND METHODS

2.1 | Study population

This study is a part of the project investigating hand eczema among nursing apprentices in Croatia with a previously described protocol.¹² In brief, all 264 nursing apprentices from three vocational schools in the Croatian capital city, Zagreb, attending their final (fifth) year of education were invited to participate. All participants were aged 18 years or older, and gave their written informed consent to be included in the study. Ethical approval was granted by the Ethical Committee of the Institute of Medical Research and Occupational Health, Zagreb, Croatia (Ethics approval number: 100-21/20-11, class: 01-18/20-02-2/1). In total, 238 apprentices (180 women, 76% and 58 men, 24%) were enrolled in the study and finished the entire study protocol (the response rate was 90.9%). Their median age was 19 years (interquartile range [IQR] 19-20 years; total range 18-21 years).

Due to the varying degree of epidemiological restrictions during the course of COVID-19 pandemic, recruitment and data collection were conducted in periods during November and December 2020 and from February to May 2021, when apprentices attended the classes in the schools and could be approached for assessments which were done in classrooms. According to their curriculum, practical work at healthcare facilities takes around half of the total teaching hours during the last 3 years of education. Collection of data on participants' habits and skin symptoms was described in detail previously.¹² It was done under the prescribed epidemiological measures and consisted of implementation of questions from the Nordic Occupational Skin Questionnaire (NOSQ-2002),¹³ and clinical examination of skin on the hands by occupational physicians, scoring the skin changes with the validated Osnabrück Hand Eczema Severity Index (OHSI).^{14,15}

2.2 | Skin barrier assessments

Hand skin TEWL and SC pH were measured on the dorsum of the hand using commercially available probes (Tewameter TM 300 probe

and pH probe; Courage + Khazaka Electronic, Cologne, Germany) with the standard procedure suggested by the manufacturer. The conditions in the classrooms could not be controlled. The median (IQR, total range) ambient temperature during measurements was 24.7°C (23.1°C–25.8°C, 19.8°C–26.8°C), and the ambient relative humidity was 34.7% (27.8%–41.3%, 25.1%–50.8%).

2.3 | Statistical analysis

Characteristics of the participants were summarized using descriptive statistics. Hand TEWL and pH values were analysed as both continuous variable (measured value) and categorical variables (values dichotomized as normal or elevated). Values above 25 g/m²/h for TEWL and above 5.5 for SC pH were considered elevated, and a sign of comprised skin barrier function, based on manufacturer recommendations. We investigated associations of hand TEWL and pH values as outcome variables with personal factors (age, sex, self-reported history of atopic dermatitis), with existing clinically determined hand skin symptoms, and with work-related factors (washing hands for more than 20 times per day, sanitizing hands with alcohol-based or other types of sanitizers, either more than 10 or 20 times per day, duration of glove use per day, either categorized in time categories 0-0.5, 0.5-2, 2-5, or >5 hours per day, or with a cut-off of at 2 hours per day), and a risk score was calculated as a sum of work-related factors as predictor variables. A risk score for each participant was calculated as a sum of the following points (in parentheses) if a habit was reported: washing hands for more than 20 times/day (1), hand sanitizing 11 to 20 times/day (1) for each type of sanitizers, hand sanitizing over 20 times/day (2) for each type of sanitizers, gloves worn hour/day from 0-0.5 (0) to over 5 (3). Significance of associations between categorical outcome and predictor variables was analysed with a Pearson chi-square test (or Fisher exact test if the subgroup frequency was <5), between continuous and categorical variables with a Mann-Whitney test, and between two continuous variables by a linear regression and Spearman correlation. After that the associations of hand TEWL and hand SC pH with relevant predictors (skin symptoms, age, sex) were simultaneously analysed in multiple linear regression models if the outcomes TEWL and pH were employed as continuous variables, or multiple logistic regression models if outcomes were employed as categorical variables. All models were adjusted for ambient temperature and ambient humidity and hand washing within 2 hours prior to measurement. The associations were considered to be statistically significant at a *P*-value of <.05. Analyses were performed with the statistical software R Studio (R Foundation, Vienna, Austria).¹⁶

3 | RESULTS

3.1 | Characteristics of the participants

Personal characteristics of the participants are shown in Table 1; age of apprentices was of narrow range and they were mostly women. Median (IQR, total range) of hand TEWL values in our study sample

TABLE 1 Characteristics of the nursing apprentices and differences in those with elevated hand TEWL/pH values

	Total study sample N = 238	Apprentices with elevated hand TEWL values (>25 g/m ² /h) N = 114	Apprentices with normal hand TEWL values N = 124	P-value (elevated vs normal TEWL)	Apprentices with elevated hand SC pH values (>5.5) N = 135	Apprentices with normal hand SC pH values N = 103	P-value (elevated vs normal pH)
Age (y), median (IQR, TR)	19 (19-20, 18-21)	20 (19-20, 18-21)	19 (19-20, 18-21)	<.001	20 (19-20, 18-21)	19 (19-20, 18-21)	.071
Women, n (%)	180 (76)	82 (72)	98 (79)	.202	110 (81)	70 (68)	.016
History of atopic dermatitis, n (%)	50 (21)	26 (22)	24 (19)	.514	28 (21)	22 (21)	.908
One or more skin changes on clinical examination, n (%)	115 (48)	65 (57)	50 (40)	.010	78 (57)	37 (36)	.001
OHSI score on clinical examination, median (IQR, TR)	0 (0-4, 0-25)	2 (0-4, 0-13)	0 (0-4, 0-25)	.022	2 (0-4, 0-25)	0 (0-2, 0-8)	<.001

Note: Bold indicate variables significantly associated with the outcomes ($P < .05$). Significance of difference tested by χ^2 test or Fisher exact test for categorical variables and Mann-Whitney test for noncategorical variables. Abbreviations: IQR, interquartile range; OHSI, Osnabrück Hand Eczema Severity Index; SC pH, stratum corneum pH; TEWL, transepidermal water loss; TR, total range.

was 23.58 g/m²/h (16.55-36.00, 3.02-70.90), and hand SC pH was 5.56 (5.20-5.85, 4.48-6.86). Considering the proportion of participants who had elevated TEWL values (>25 g/m²/h) indicating strained skin condition, it was noted that 114 participants (48%) were in this category. Similarly, a high proportion of participants had pH values elevated above physiological levels (135 participants, 57%).

3.2 | Associations of hand TEWL and pH with personal factors

Hand TEWL values were significantly positively associated with participants' age: for each increasing year of participants' age, hand TEWL values were higher by 4.08 g/m²/h ($P = .001$). The same trend of association was noted when it was investigated using Spearman correlation ($\rho = 0.209$, $P = .001$), and when TEWL values were dichotomized as elevated vs normal values (Table 1; Mann-Whitney test, $P < .001$). SC pH was significantly positively associated with female sex: median (IQR, total range) was 5.61 (5.31-5.91, 4.58-6.86) among women, in comparison with 5.39 (5.00-5.60, 4.48-6.32) among men (Mann-Whitney test, $P = .001$). The same trend was noted when pH values were dichotomized as elevated vs normal (Table 1; χ^2 test, $P = .016$). Self-reported history of atopic dermatitis judged on the basis of the report of itchy rash in skin folds, behind ears, around eyes (NOSQ-2002) was not significantly associated with hand TEWL or pH, studied either as a continuous or as a dichotomized variable.

3.3 | Associations with hand skin symptoms

Parameters of skin barrier function were significantly associated with hand skin symptoms. Overall, in 115 participants (48%) one or more type of skin changes on hands were found on the clinical examination (erythema, infiltration, desquamation, papules, vesicles, or fissures). Around 30% higher median TEWL value was found in those with one or more skin changes than in those with healthy skin; specifically, median (IQR, total range) hand TEWL values on unaffected skin were 26.54 g/m²/h (18.82-36.21, 5.56-70.90) among those with skin symptoms, in comparison to 20.57 g/m²/h (15.11-34.12, 3.02-60.76) among those without any symptoms (Mann-Whitney test, $P = .14$). In addition, significantly higher proportion of participants with hand skin symptoms had elevated hand TEWL values: 65 of 115 (57%) participants with skin symptoms and 49 of 123 (40%) without symptoms had TEWL over 25 g/m²/h (χ^2 test, $P = .010$). Table 1 shows proportions of hand skin symptoms among participants with elevated or normal hand TEWL values. We further investigated associations of specific types of skin symptoms with individual skin integrity as indicated by TEWL (Figure 1). Only infiltration was significantly associated with elevated TEWL values (Figure 1, χ^2 test, $P = .001$). Regarding hand SC pH, the same trend of associations with having one or more skin symptom was noted; specifically, median (IQR, total range) SC pH values were 5.63 (5.38-5.90, 4.58-6.46) among those with skin symptoms, in comparison to 5.47 (5.06-5.80, 4.48-6.86)

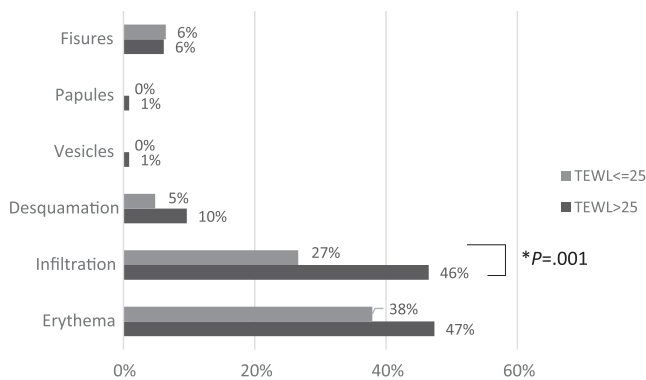


FIGURE 1 Comparison of hand skin symptoms found in nursing apprentices with strained skin condition (hand TEWL >25 g/m²/h; N = 114) and those with normal hand TEWL values (N = 124). TEWL values above 25 g/m²/h were considered elevated. Significance of difference tested by χ^2 test. Differences with regard to papules and vesicles were not tested due to extremely small numbers. TEWL, transepidermal water loss

among those without any symptoms (Mann-Whitney test, $P = .004$). In addition, a significantly higher proportion of participants with hand skin symptoms had elevated hand pH values: 78 of 115 (68%) participants with skin symptoms and 57 of 123 (43%) without symptoms had pH higher than 5.5 (χ^2 test, $P = .001$). Table 1 shows proportions of hand skin symptoms among participants with elevated or normal hand pH values. Considering the severity of symptoms, we noted that the OHSI score was significantly positively correlated only with hand SC pH ($P = .005$, Spearman rho = 0.260), and not with TEWL as a continuous variable. However, the OHSI score was significantly positively associated with both bioengineering parameters when TEWL and pH were analysed as dichotomized variables (Table 1).

3.4 | Associations with work-related factors

Besides personal factors and skin symptoms, we investigated associations of skin barrier function with work-related factors. Overall,

TABLE 2 Characteristics of the nursing apprentices and differences between those with elevated hand TEWL value and with normal TEWL

	Total study sample N = 238	Apprentices with elevated hand TEWL values (>25 g/m ² /h) N = 114	Apprentices normal hand TEWL values N = 124	P-value (elevated vs normal)	Apprentices with elevated hand SC pH values (>5.5 N = 135)	Apprentices normal hand SC pH values N = 103	P-value (elevated vs normal)
Washing hands > 20 times/d, n (%)	30 (13)	9 (8)	21 (17)	.036	9 (8)	21 (17)	.113
Sanitizing hands with alcohol-based sanitizers, n (%)							
0-10 times per day	97 (41)	48 (42)	49 (39)	.683 ^a	56 (41)	41 (40)	.311 ^a
11-20	76 (32)	38 (33)	38 (31)		47 (35)	29 (28)	
>20	65 (27)	28 (25)	37 (30)		32 (24)	33 (32)	
Sanitizing hands with other types of sanitizers, n (%)							
0-10 times per day	194 (82)	97 (85)	97 (78)	.854	115 (85)	79 (77)	.095
11-20	44 (18)	17 (15)	27 (22)		20 (15)	24 (23)	
>20	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	
Gloves worn (h/d), n (%)							
0-0.5	28 (12)	12 (11)	16 (13)	.660 ^a	18 (10)	10 (13)	.427 ^a
0.5-2	115 (48)	54 (47)	61 (49)		64 (49)	51 (47)	
2-5	86 (36)	42 (37)	44 (36)		50 (35)	36 (37)	
>5	9 (4)	6 (5)	3 (2)		3 (6)	6 (2)	
Risk score ^b , median (IQR, TR)	3 (1-4, 0-8)	3 (2-3, 0-7)	3 (1-4, 0-8)	.612	2 (1-3, 0-7)	3 (2-4, 0-8)	.160

Note: Significance of difference tested by χ^2 test or Fisher exact test for categorical variables and Mann-Whitney test for noncategorical variables.

Abbreviations: IQR, interquartile range; SC pH, stratum corneum pH; TEWL, transepidermal water loss; TR, total range.

^aConsidering the distribution of all categories between the groups with elevated hand TEWL value and with normal TEWL.

^bTo investigate associations with aggregated exposure, 'risk score' was calculated for each participant as a sum of the work-related factors using the following points (in parentheses): washing hands for >20 times/d (1), hand sanitizing 11-20 times/d (1) for each type of sanitizers, hand sanitizing >20 times/d (2) for each type of sanitizers, gloves worn h/d from 0-0.5 (0) to >5 (3).

participants reported spending a median (IQR, total range) of 13 days/mo (12-20, 3-30), and 6 h/d (5-7, 0.5-10) on practical training in hospitals. Reported durations of practical training were not significantly associated with hand TEWL or pH values. None of the studied work-related parameters (frequencies of hand washing and hand sanitizing, duration of glove use) were significantly associated with hand TEWL or pH values, with the exception of hand washing that had an unexpected direction of association. Proportions of each work-related risk factor among participants with elevated and normal TEWL/pH are given in Table 2.

3.5 | Adjustments for ambient factors

The possibility that ambient factors that we could not control distorted found associations was investigated by multiple logistic and linear regression models adjusted for room air temperature and relative humidity, and hand washing prior to skin-bioengineering measurement. Only the associations with SC pH remained significant when controlling for these confounding factors (Table 3): women and those with skin symptoms had over two times higher odds of having elevated pH (Table 3; $P = .004$ and $.001$, respectively; P model $< .001$). The same significant trend was noted when pH was investigated as a continuous variable (coefficient for having one or more skin changes on clinical examination = 0.17, 95% confidence interval 0.05-0.28, $P = .006$, coefficient for female sex = 0.27, 95% confidence interval 0.14-0.40, $P < .001$; P model $< .001$, pseudo $R^2 = 0.140$).

4 | DISCUSSION

The main finding of our cross-sectional study on final-year nursing apprentices is that around half of them have compromised hand skin barrier function as indicated with elevated TEWL values (>25 g/m²/h) and pH values above physiological levels (>5.5). Elevated SC pH was robustly and independently of ambient conditions associated with skin symptoms on hands determined by clinical examination, but hand

TEWL values on unaffected skin were predominantly susceptible to ambient air humidity and consequently were not reliably associated with skin symptoms in this field study.

A period of education chosen for this study seems to have a great influence on the found associations of TEWL with skin symptoms. Basal TEWL values measured before the beginning of practical training do not seem to predict later hand skin symptoms,^{3,17} but an increase in TEWL during first year of education was associated with having hand skin symptoms in the final year.¹⁷ In a very recent preventive study in Romania by Moldovan et al,¹⁸ which included nursing apprentices of all study years, a significant increase of approximately 50% in mean hand TEWL values was observed after 3 months of internship training in hospitals. By contrast, in apprentices who were provided with an educational lecture on dermatitis prevention and with skin emollients, a decrease in TEWL values was seen.¹⁸ Considering the final year alone, similar to our study, Schmid et al¹⁷ reported that hand TEWL values among final-year German apprentices were significantly increased in those with symptoms of hand dermatitis at clinical examination in comparison to apprentices without symptoms. Although direct comparison is difficult, it should be noted that the median hand TEWL value in our study (23.58 g/m²/h) was considerably higher than mean values reported in the mentioned earlier studies (specifically, 13.55 g/m²/h among final-year apprentices in the German study by Schmid et al,¹⁷ and 13 g/m²/h among apprentices at last examination in the Dutch study by Held et al,³ but corresponds with the mean value among apprentices at last examination in the recent Romanian study by Moldovan et al (28.36 g/m²/h).¹⁸ Increased hand hygiene during practical training in the COVID-19 pandemic could have affected skin barrier condition of apprentices in comparison with studies from the first decade of the 21st century. In our study, a considerable proportion (40%) of nursing apprentices without hand skin symptoms had TEWL values over 25 g/m²/h, indicating damaged skin barrier.

Although the range of participants' age was narrow (18-21 years), age was significantly positively correlated with TEWL, indicating that cumulative exposure starts to impair skin barrier function already during the apprenticeship. Reported daily and monthly duration of practical work were not significantly associated with hand TEWL values, nor

TABLE 3 Results of the multiple logistic regression models with parameters of skin barrier function as outcomes (N = 238)

Predictors:	Hand TEWL > 25 g/m ² /h <i>P</i> model < .001 Pseudo $R^2 = 0.167$			Hand SC pH > 5.5 <i>P</i> model = .001 Pseudo $R^2 = 0.129$		
	OR	95% CI	<i>P</i> -value	OR	95% CI	<i>P</i> -value
One or more skin changes on clinical examination vs no skin changes	1.39	0.79-2.44	.252	2.53	1.44-4.53	.001
Age (years)	1.25	0.73-2.17	.415	1.47	0.87-2.51	.156
Female vs male sex	0.78	0.41-1.49	.456	2.59	1.38-4.98	.004
Ambient air temperature during measurement (°C)	1.16	0.98-1.38	.087	0.96	0.81-1.14	.665
Ambient air relative humidity during measurement (%)	0.94	0.88-0.99	.023	1.02	0.96-1.08	.532
Washing hands within 2 h prior to measurement (yes/no)	1.61	0.87-3.01	.128	1.57	0.86-2.87	.144

Note: Bold indicate variables significantly associated with the outcomes ($P < .05$).

Abbreviations: CI, confidence interval; OR, odds ratio; SC pH, stratum corneum pH; TEWL, transepidermal water loss.

were the separate work-related risk factors. The only significant association, which was that elevated hand TEWL values were associated with less hand washing, is of unexpected trend and probably a statistical artefact due to the small number of participants in the subcategories. Information could have been further diluted by categorical questions on the average frequencies of habits, according to the Nordic occupation skin questionnaire we used. Lastly, because previous studies found increased TEWL in atopic skin,¹⁰ we deemed it important to investigate this association further among participants with high work-related exposures to skin hazards, but we found no significant association of hand TEWL values with a self-reported history of atopic dermatitis, supporting the importance of environmental factors in the deterioration of skin barrier function in nurse apprentices. This was similar to the finding among Croatian hairdresser apprentices that a history of atopy was also not significantly associated with hand TEWL.¹⁹

In our study, elevated SC pH was significantly associated with hand skin symptoms determined by clinical examination. Acidic pH is important for normal skin barrier function for several reasons. Enzymes involved in skin lipid synthesis, proper lamellar arrangement of barrier lipids, and the keratinization process are pH dependent.²⁰ Various endogenous factors can influence pH including ethnicity, age, and sex.⁹ To the best of our knowledge, SC pH in European nursing apprentices has not been investigated before, although pH was investigated among French healthcare workers (predominately nurses) in the context of hand sanitizing.²¹ One study on South African nursing apprentices investigated pH values only with respect to their race.²² Our participants were White and their age was of a narrow range and not associated with hand SC pH. Women in our study had significantly higher SC pH than men. Overall, the association with sex is still inconclusive in the literature and greatly dependent on the test site.^{20,23,24} Specifically, a German study on healthy adults found higher SC pH on the dorsum of women's hands in comparison to men,²⁵ which is in line with our results. Varying results have been reported regarding other test sites. For example, a Danish study found lower pH on the forearms of women compared with men,²⁶ but a German study found the opposite trend.²⁷ Results of our multiple logistic regression model, by which we investigated associations of relevant predictors simultaneously, confirmed both female sex and hand skin symptoms were independently associated with elevated SC pH on the unaffected skin. Regarding work-related habits, as with TEWL, we found no significant association of frequencies of washing and sanitizing hands and duration of glove use with hand SC pH values, likely due to the reasons discussed above. Finally, because increased pH was found in children with atopic dermatitis even on the unaffected skin,²⁸ we wanted to investigate the association of a history of atopic dermatitis with elevated SC pH; however, in our study sample there was no significant association.

Besides the aforesaid limitations, the main limitation of our study was that skin-bioengineering measurements were performed in vocational schools where ambient air temperature and humidity could not be controlled due to the lack of air conditioning in the appointed classrooms. The aforementioned previous studies on nursing apprentices were also performed in field conditions.^{3,17,18} Notwithstanding the usefulness of TEWL measurement as a screening tool for detecting early, subclinical skin damage, authors of these studies generally share a concern that the

utility of single measurement in field conditions is questionable because obtaining optimal circumstances for TEWL analysis in the field is difficult. This problem has been further addressed in a recent review by Jansen van Rensburg et al²⁹ who investigated reports from a wide variety of occupational settings, including hairdressing, metal, food, and printing industries. They noted that temperature and humidity reported were highly variable between the studies, and their overall conclusion was that studies that aimed at using bioengineering methods to measure acute changes in skin barrier function showed much more conclusive results than those wanting to utilize these measurements as skin disease predictors. Steps can be taken to ensure higher reliability. Ideal conditions would have been to measure TEWL in controlled laboratory conditions with room temperature of $21 \pm 1^\circ\text{C}$, relative air humidity of $50\% \pm 5\%$ relative humidity, and with participants' acclimatization to the standardized room air conditioning. This should be recommended for future studies employing TEWL measurement to exclude the possibility of measuring skin surface water loss instead of transepidermal water loss, in nonstandardized ambient conditions. However, since these conditions were out of our control during the field measurement, in statistical analysis we adjusted for ambient air temperature and humidity recorded during measurements, and prior hand washing reported by participants. Associations of SC pH with skin symptoms was not affected when adjusting for measurement circumstances, and could therefore be considered a reliable finding, but TEWL was greatly affected by ambient air humidity. In summary, pH measurement was shown to be a bioengineering method suitable for field conditions, and with a general advantage of quick measurement, it should be employed more in future field studies.

In conclusion, our results support findings about the increased skin barrier damage in healthcare workers and apprentices due to the intense hand hygiene regimen implemented during the COVID-19 pandemic, even in those without clinical skin changes. Therefore, there is clearly a need for increasing health promotion in terms of hand eczema. Existing recommendations for skin care should be more promoted in healthcare workers and even apprentices. Our data on proportions of participants with impaired skin barrier function and skin changes could be used as real-life examples giving more impact to preventive messages. Data about the significant association of hand skin symptoms with barrier function parameters measured on unaffected skin justify promoting skin-bioengineering measurements as methods for early detection of acute skin changes, which could aid clinical skin assessments and timely prevention of work-related hand dermatitis. Measurement of SC pH was shown to be less sensitive to field conditions than measurement of TEWL, and should be employed more in future field studies.

CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

AUTHOR CONTRIBUTIONS

Željka Babić: Conceptualization (equal); data curation (equal); formal analysis (lead); investigation (equal); methodology (equal); writing – original draft (lead); writing – review and editing (equal). **Franka Šakić:** Data curation (lead); investigation (equal); methodology (equal); project administration (lead); writing – review and editing (equal). **Zrinka Franić:** Data curation (equal); investigation (equal); methodology

(equal); writing – review and editing (equal). **Jelena Macan:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (lead); methodology (equal); resources (equal); supervision (lead); writing – original draft (equal); writing – review and editing (equal).

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