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Short-term skin reactions following use of N95 respirators and medical masks

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Abstract

Background: In the context of the COVID-19 pandemic, cases of adverse skin reactions related to the wearing of masks have been observed.

Objectives: To analyze the short-term effects of N95 respirators and medical masks, respectively, on skin physiological properties and to report adverse skin reactions caused by the protective equipment.

Methods: This study used a randomized crossover design with repeated measurements. Twenty healthy Chinese volunteers were recruited. Skin parameters were measured on areas covered by the respective masks and on uncovered skin 2 and 4 hours after donning, and 0.5 and 1 hour after removing the masks, including skin hydration, transepidermal water loss (TEWL), erythema, pH, and sebum secretion. Adverse reactions were clinically assessed, and perceived discomfort and non-compliance measured.

Results: Skin hydration, TEWL, and pH increased significantly with wearing the protective equipment. Erythema values increased from baseline. Sebum secretion increased both on the covered and uncovered skin with equipment-wearing. There was no significant difference in physiological values between the two types of equipment. More adverse reactions were reported following a N95 mask use than the use of a medical mask, with a higher score of discomfort and non-compliance.

Conclusions: This study demonstrates that skin biophysical characters change as a result of wearing a mask or respirator. N95 respirators were associated with more skin reactions than medical masks.

KEYWORDS
adverse skin reaction, N95 respirator, medical mask, skin biophysical property

1 | INTRODUCTION

SARS-CoV-2 is a novel coronavirus that emerged in late 2019. The resulting COVID-19 disease has been labelled a public health emergency of international concern by the World Health Organization.[1] Globally, millions of confirmed cases of COVID-19 have been reported; however, understanding of the transmission risk is incomplete. Person-to-person spread is thought to occur mainly via respiratory droplets and contact.[2]

Healthcare workers who care for COVID-19 patients are at great risk of contracting the disease and, therefore, it is necessary for them to wear personal protective equipment. Respiratory protective

Abbreviations: MCA, medical mask-covered area; MUA, medical mask-uncovered area; NCA, N95-coverd area; NUA, N95-uncovered area; RPE, respiratory protective equipment; TEWL, transepidermal water loss.

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equipment (RPE), such as respirators and medical masks, are often worn for hours at a time. Even though the usefulness of wearing masks in the context of the COVID-19 pandemic is still largely unknown, it has become more and more common to also see people wearing masks in public recently, particularly in Asia.[3,4]

With respect to the use of RPE, dermatologists at our hospital have observed isolated cases of adverse skin reactions to this equipment. Skin reactions such as contact dermatitis, acne, facial itch, and rash from RPE use have been reported.[5-8] However, there is insufficient information on various skin reactions to the use of RPE. Our aim was to analyze the short-term effects of N95 respirators and medical masks on skin physiological properties and to report on adverse skin reactions caused by the equipment.

2 | METHODS

This study used a repeated-measures, crossover, random design. Healthy participants with no history of skin diseases or skin changes on test sites were included in the trial. Exclusion criteria were use of corticosteroids and immunomodulators during one month before inclusion and during the trial, non-adherence to the trial protocol, pregnancy, lactation, and excessive and deliberate exposure to solar ultraviolet radiation.

The study protocol was approved by the Institutional Ethics Committee of West China Hospital, Sichuan University (No.2020-225) and all participants gave written informed consent before entering the trial. This trial ran from February to April 2020 and was registered at ChiCTR as ChiCTR2000031977.

2.1 | Interventions

After being evaluated for eligibility, all participants were followed for two test days (intersession interval >1 day). Participants were randomly assigned to wear either an N95 respirator (3M Corporation, St Paul, Minnesota) or a surgical mask (Winner Medical, Huanggang, Hubei, China) for the first test day. During the second test day, participants were crossed over to the other intervention. Participants were initially educated regarding medical masks and N95 respirators, according to the guidance from 3M, and passed the seal-check when wearing N95 respirators.[9,10]

The participants gently washed their faces with water and were acclimatized to an indoor environment without RPE for 60 minutes. After their baseline levels were measured, they wore the RPE for 2 hours, after which measurements were taken again. After a 1-hour interval off RPE, they wore the masks for another 4 hours. Measurements were taken immediately after the masks were taken off and then after two intervals of 30 minutes each (Figure S1). The measurements were completed within 10 minutes at each time point.

Additionally, adverse reactions were assessed clinically and via interview by a trained professional blinded to the type of mask which had been used. Skin symptoms to RPE wearing, including erythema, facial indentation, itch, pain or prickling, and burning, were recorded. Furthermore, reactions of the respiratory tract and eyes, such as itchy nose, sneezing, running nose, stuffy nose, itchy throat, cough, chest tightness and shortness of breath, itchy eyes, and watering eyes were also recorded. Perceived discomfort and non-compliance were measured using a modified Comfort Scale,[11] consisting of three Likert scales ranging from 1–5 points.

2.2 | Instruments and measurement

Skin parameters were assessed using non-invasive bioengineering measurements. Facial skin was divided into an RPE-covered area and an RPE-uncovered area, both of which were measured at the same time point. The Tewameter TM300, Corneometer CM825, Mexameter MX18, Skin-pH-Meter PH 905, and Sebumeter SM 815 (Courage+Khazaka, Cologne, Germany) were used to determine transepidermal water loss (TEWL), skin hydration, erythema, pH, and sebum secretion. All measurements were taken in accordance with the manufacturers' guidelines on designated areas of the face (Figure S2).[12-15]Clinical pictures were taken with VISIA skin imaging equipment (Canfield Scientific, Fairfield, New Jersey). The room where the measurements were taken was kept at a constant temperature (20–22°C) and relative humidity range (40%–60%).

2.3 | Statistical analysis

The statistics package SPSS version 20.0 (IBM/SPSS; Armonk, New York) was used to evaluate the significance level. A *P*-value of <.05 was considered statistically significant. The skin physiological properties of RPE wearing by time and group were analyzed using repeated measures analysis of variance (RM-ANOVA) with post-hoc Bonferroni correction. The comparison of skin symptoms related to the N95 respirators and medical masks were compared by Fisher's exact test. A paired *t*-test was carried out to determine whether there was a difference in the discomfort and non-compliance scores between the two kinds of RPE.

3 | RESULTS

Twenty Chinese participants [two (10%) male] enrolled in and completed the study. The mean (±SD) age was 34.3 (±11.5) years.

3.1 | Skin properties

At baseline, there were no significant differences in skin hydration, TEWL, erythema, pH, or sebum values of the RPE-covered and uncovered areas. The comparison of skin properties of different RPE type and measurement time are shown in Figure 1. There was no

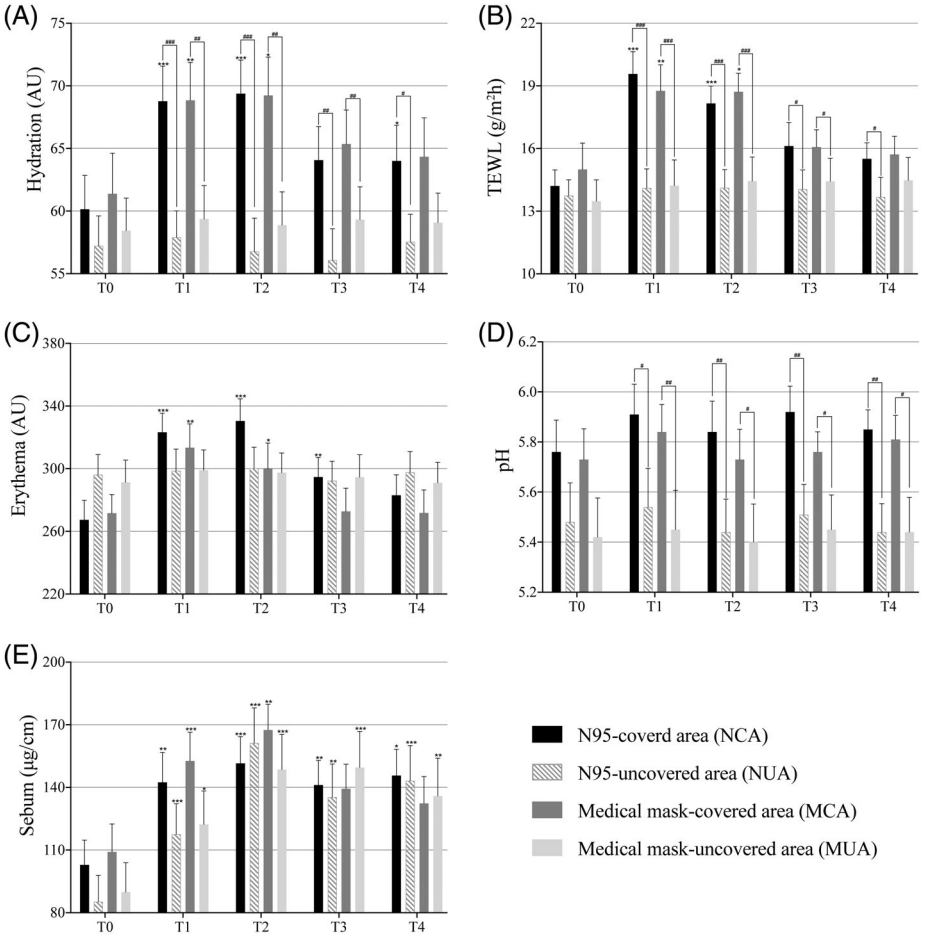

FIGURE 1 Skin properties on the face, including (**A**) hydration, (**B**) transepidermal water loss (TEWL), (**C**) erythema, (**D**) pH, and (**E**) sebum values. *P*-values <.05 are significant. **P* < .05, ***P* < .01, ****P* < .001, compared with baseline; #*P* < .05, ##*P* < .01, ###*P* < .001, compared with the uncovered area. T0: Baseline, T1: 2 hours after putting on the respiratory protective equipment (RPE); T2: 4 hours after putting on RPE; T3: 0.5 h after taking off RPE; T4: 1 hour after taking off RPE

significant difference between the physiological values on the N95-covered and medical mask-covered areas at any time point.

The skin hydration level on the N95-coverd area (NCA) increased significantly compared to that on the N95-uncovered area (NUA) after wearing the RPE for 2 and 4 hours, and the difference persisted at 0.5 and 1 hour (*P* < .001 at 2 and 4 hours, *P* < .01 at 0.5 hour post removal, *P* < .05 at 1 hour post removal). Hydration values measured on the medical mask-covered area (MCA) were higher than the values on the medical mask-uncovered area (MUA) after wearing the RPE for 2 and 4 hours (*P* < .01), and 0.5 hour post removal. However, after 60 minutes without RPE, the hydration values on MCA decreased and showed no difference with MUA. When compared with baseline, the skin hydration level on the NCA increased (*P* < .001 at 2 and 4 hours), and then decreased after removing the respirators; however, the change continued at 1 hour post removal (*P* < .05). The increase of hydration level on the MCA was significant at 2 and 4 hours, but after removal of the masks, the values decreased to the baseline level.

The TEWL values on the NCA were significantly higher than the values on the NUA after wearing the RPE for 2 and 4 hours (*P* < .001), and the difference lasted 0.5 and 1 hour post removal (*P* < .05). The TEWL on the MCA increased significantly (*P* < .001, compared with the MUA) after 2 and 4 hours with medical masks, and 0.5 hour with masks (*P* < .05, compared with the MUA), but after removing the masks for 1 hour, the TEWL values were decreased and showed no significant difference with that of the MUA. When compared with baseline, the TEWL level on the RPE-covered area increased after donning the equipment (N95 respirators: *P* < .001 at 2 and 4 hours; medical masks: *P* < .01 at 2 hours, *P* < .05 at 4 hours), whereas it decreased to the baseline level after removing the equipment.

After wearing the RPE for 2 and 4 hours, the skin erythema level on the NCA increased significantly relative to the level of the baseline (*P* < .001), and the difference persisted at 0.5 hour post removal (*P* < .01), but no significant difference was shown 1 hour after removal of the RPE. With the RPE, the erythema values on the MCA were significantly higher than those at the baseline (*P* < .01 at 2 hours, *P* < .05 at 4 hours), and after removal of the RPE, the values decreased (*P* > .05). However, there was no significant difference between the erythema values on the RPE-covered and uncovered areas at any time point.

After wearing the RPE, the skin pH values on the RPE-covered area were higher than the values on the RPE-uncovered area (N95 respirators: *P* < .05 at 2 hours, *P* < .01 at 4, 0.5 and 1 hour post removal; medical masks: *P* < .01 at 2 hours, *P* < .05 at 4, 0.5 and 1 hour post removal). However, there were no significant differences between pH levels at follow-up relative to the baseline.

With N95 respirators, sebum secretion increased significantly compared to baseline on both the RPE-covered and uncovered areas (NCA: *P* < .01 at 2 hours, *P* < .001 at 4 hours; NUA: *P* < .001 at 2 and

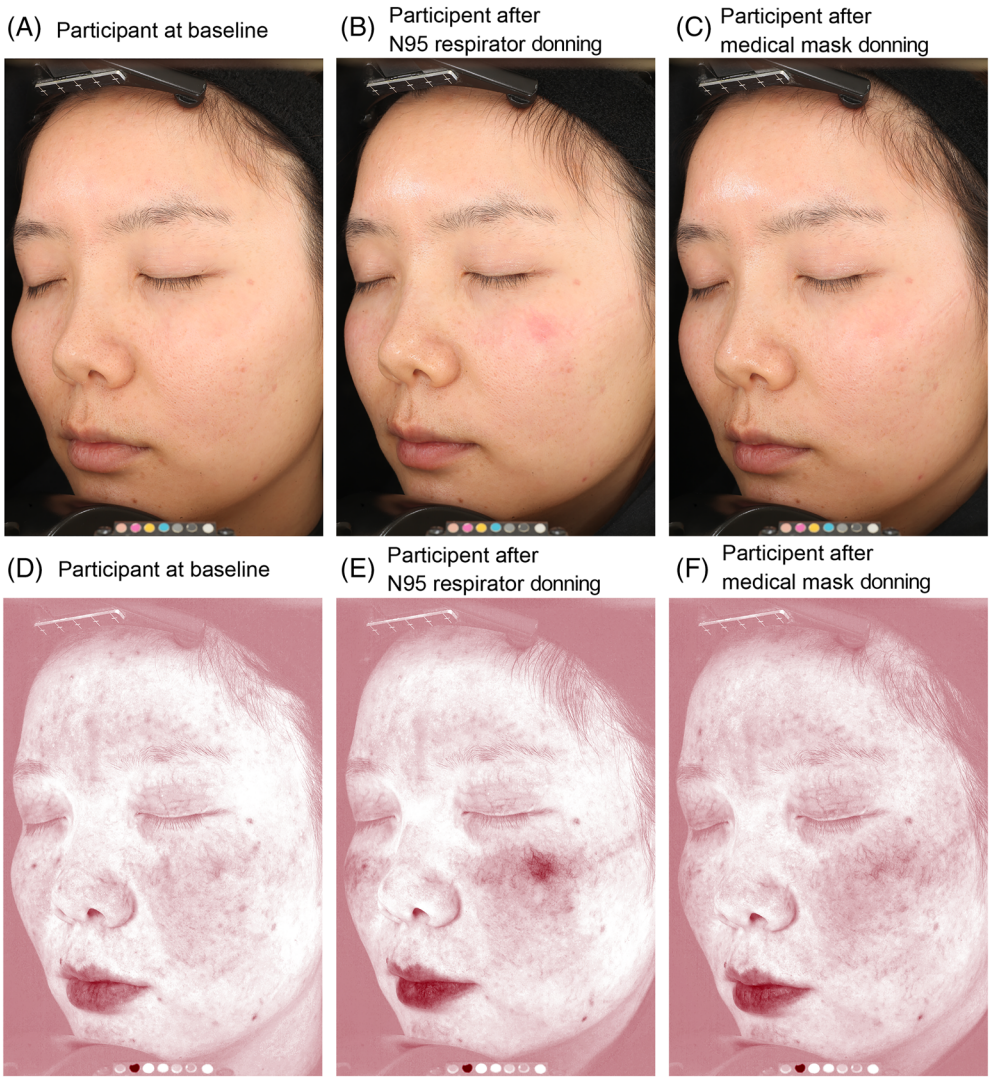

FIGURE 2 Clinical photographs were taken at (**A**,**B**) baseline, (**C**,**D**) after removal N95 respirator, and (**E**,**F**) medical mask

TABLE 1 Reported N95 Respirator and medical mask-related symptoms

Anatomic site	Clinical feature, no. (%) with data	N95 respirator (n = 20) n (%)	Medical mask (n = 20) n (%)	*P*-value
Skin[a]	Redness or erythema	17 (85)	3 (15)	<.001
	Facial indentation	19 (95)	0 (0)	<.001
	Itch	12 (60)	7 (35)	.21
	Pain or prickling	6 (30)	0 (0)	.02
	Burning	3 (15)	1 (5)	.61
Respiratory tract[b]	Itchy nose/sneezing/running nose/stuffy nose/itchy throat/cough	3 (15)	0 (0)	.23
	Chest tightness and shortness of breath	8 (40)	4 (20)	.3
Eyes	Itchy eyes/streaming eyes	2 (10)	1 (5)	> .99

[a]Number of participants with adverse skin reaction = 20, 10 (N95 respirator, medical mask).
[b]Number of participants with adverse respiratory reaction = 10, 4 (N95 respirator, medical mask).

4 hours) and the difference persisted after removal (NCA: $P < .01$ at 0.5 hour post removal, $P < .05$ at 1 hour post removal; NUA: $P < .01$ at 0.5 hour post removal, $P < .001$ at 1 hour post removal). With medical masks, sebum levels on both areas were significantly higher than those of the baseline (MCA: $P < .001$ at 2 hours, $P < .01$ at 4 hours; MUA: $P < .05$ at 2 hours, $P < .001$ at 4 hours), and after removing the RPE, the differences on the MUA lasted for at least 1 hour ($P < .001$ at 0.5 hour post removal, $P < .01$ at 1 hour post

TABLE 2 Discomfort and non-compliance scores

Item (Likert scale 1–5)	N95 respirator (n = 20) mean (±SD)	Medical mask (n = 20) mean (±SD)	*P* value
Score of Comfort[a]	3.4 (1.4)	1.4 (0.8)	<.001
Score of Touching[b]	3.3 (1.4)	1.8 (1.4)	<.001
Score of Removal[c]	3.5 (1.8)	1.8 (1.4)	<.001
In total	10.2 (4.3)	4.9 (3.3)	<.001

[a]Score refers to "The mask or respirator is uncomfortable." 1, most comfortable you have ever felt to 5, most uncomfortable you have ever felt.
[b]Score refers to "I want to touch or adjust the mask or respirator while wearing." 1, you never want to touch or adjust the mask to 5, you always want to touch or adjust the mask.
[c]Score refers to "I want to take off the mask or respirator." 1, you never want to take off the mask to 5,= you always want to take off the mask.

removal). There was no significant difference between the sebum values on the RPE-covered and uncovered areas at any time point.

3.2 | Clinical symptoms

Clinical pictures of one participant are shown in Figure 2. All participants reported adverse skin reactions with the use of the N95 respirator, which were significantly greater than reactions caused by the medical mask (10 participants, 50%, $P < .001$). There was no significant difference between the number of participants who reported respiratory tract symptoms with the two different kinds of RPE. One participant had eye symptoms with the medical mask and two participants had eye symptoms with N95 respirator (Table 1).

3.3 | Discomfort and non-compliance scores

Discomfort and non-compliance levels of wearing N95 respirators compared to medical masks were assessed for three aspects using a 5-point Likert scale. Scores were aggregated to generate a "discomfort and non-compliance score" with a range of 3–15 (Table 2). The mean score of N95 respirators was 10.2 (±SD 4.3), while the mean score of medical masks was 4.9 (±SD 3.3), with a statistically significant difference ($P < .001$).

4 | DISCUSSION

In the context of the COVID-19 pandemic, the issue of wearing masks has become a focus of debate. Increasing numbers of agencies and governments, including the US Centers for Disease Control and Prevention, are advocating that the general population wears masks;[16] but others, such as the World Health Organization and Public Health England are not.[17] While the use of masks in healthcare settings is clearly essential to protect frontline workers,[18] much remains unknown about the usefulness of population level mask wearing.

We observed that the level of skin hydration, TEWL, erythema, pH, and sebum secretion increased after participants wore the masks and respirators; these values subsequently decreased after RPE-removal. Even though no statistically significant difference in the values have been found between the two kinds of mask-covered skin, it takes more time for the N95-covered skin to return to initial levels of skin hydration and erythema and to decrease the TEWL levels to those of uncovered skin.

These skin properties can be influenced by a number of endogenous and external factors, such as anatomic site, age, sex, circadian rhythms, temperature, and humidity.[19,20] Because of expiration and an occlusion effect on the masked skin, the local environment has been changed. The temperature and humidity could be increased, comparable with diapered skin to some extent, except for the presence of fecal and urinary waste. The increased temperature and excessive moisture and friction all contribute to the local disruption of the skin barrier function.[21]

Our results show that skin reactions to the RPE are characterized by a compromised skin barrier function, as indicated by increased TEWL and pH. Measuring TEWL is a non-invasive method that allows for the evaluation of the skin barrier function. However, we determined that over-hydrated skin causes sweat and that areas with an increased amount of sweat resulted in a high TEWL. The normal acidic pH of the stratum corneum has an important role in the formation and maintenance of the permeability barrier and in antimicrobial defense. Skin pH was significantly more alkaline on masked areas, which is consistent with previous findings of changes on diapered skin.[21]

Erythema occurs as a result of cutaneous blood vessel dilation and increased blood flow to the skin. Although transient facial erythema in this study could be observed as a normal, neurologically mediated response to heat or pressure exposure, inflammation can lead to longer-lasting erythema. It was previously shown in a study imitating the occlusive environment of diapered skin that prolonged occlusion in the presence of digestive enzymes induces skin erythema.[22]

Cunliff et al[23] found that sebum secretion becomes elevated by 10% as the local temperature increases by 1°C. In this study, it is interesting to note that the sebum level increased not only on the masked skin, but also on the uncovered skin. Sebum secretion changed with the circadian rhythm,[24] which might provide an alternative explanation for the result.

Previously, N95 and surgical masks have been documented to contain formaldehyde and other preservatives, which might induce contact dermatitis.[6,7] Friction, warmth, and moisture from respiration may enhance symptoms.[8] The overall prevalence of skin damage caused by enhanced infection-prevention measures was 526 of 542 (97.0%) among first-line healthcare workers.[25]A survey in Singapore[5] reported 109 of 307 (35.5%) staff who used N95 respirators regularly reported adverse skin reactions, which included acne (59.6%), facial itch (51.4%), and rash (35.8%). This is consistent with our findings on the changes in skin barrier function and sebum secretion. In that study, the most frequent adverse reactions to the

respirators and masks were pressure related. Symptoms suggesting allergic or irritant reactions (eg itch, redness, and rashes) were also common.

Although N95 respirators appeared to have a protective advantage over medical masks in laboratory settings, meta-analysis showed that there were insufficient data to determine definitively whether N95 respirators are superior to surgical masks in protecting healthcare workers against transmissible acute respiratory infections in clinical settings.[26,27] N95 masks were associated with more reactions than medical masks,[28] which might be related to the higher air impermeability and more pronounced local pressure compared to medical masks. Our survey revealed higher non-compliance concerning respirator use owing to discomfort, which could enable transmission of pathogens.

Mask and respirator interventions were generally reported to be cost saving or cost-effective when compared to no intervention or other control measures; however, the evaluations had important limitations.[29] Further, it has been reported that the incremental cost of preventing a clinical respiratory illness case with continuous use of N95 respirators, when compared to medical masks, ranged from US $490–$1230.[30] However, the cost of skin problems related to masks and respirators have not yet been taken into consideration.

Limitations of this study include the small sample size and short period of the study. To ensure the respirators were worn correctly, it is suggested that fit testing is carried out before use. As we were not equipped with material for fit testing, we trained the participants and conducted a seal-check before the test to make sure, as far as possible, that the RPE was used appropriately.

5 | CONCLUSIONS

This study demonstrates that skin hydration, TEWL, erythema, pH, and sebum secretion increased after wearing masks and respirators. There was no significant difference between the physiological values on the N95-covered and medical mask-covered areas at any time point. However, N95 masks were associated with more skin reactions than medical masks, and with higher discomfort and non-compliance scores.

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AUTHOR CONTRIBUTIONS

Wei HUA: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualization; writing-original draft. **Ying Zuo:** Data curation; formal analysis; software; writing-original draft. **Ruoyu Wan:** Data curation; formal analysis; project administration; software. **Lidan Xiong:** Formal analysis; methodology; software. **Jie Tang:** Data curation; investigation; software. **Lin Zou:** Investigation; software. **Xiaohong Shu:** Investigation; software. **Li Li:** Conceptualization; data curation; funding acquisition; supervision; writing-review and editing.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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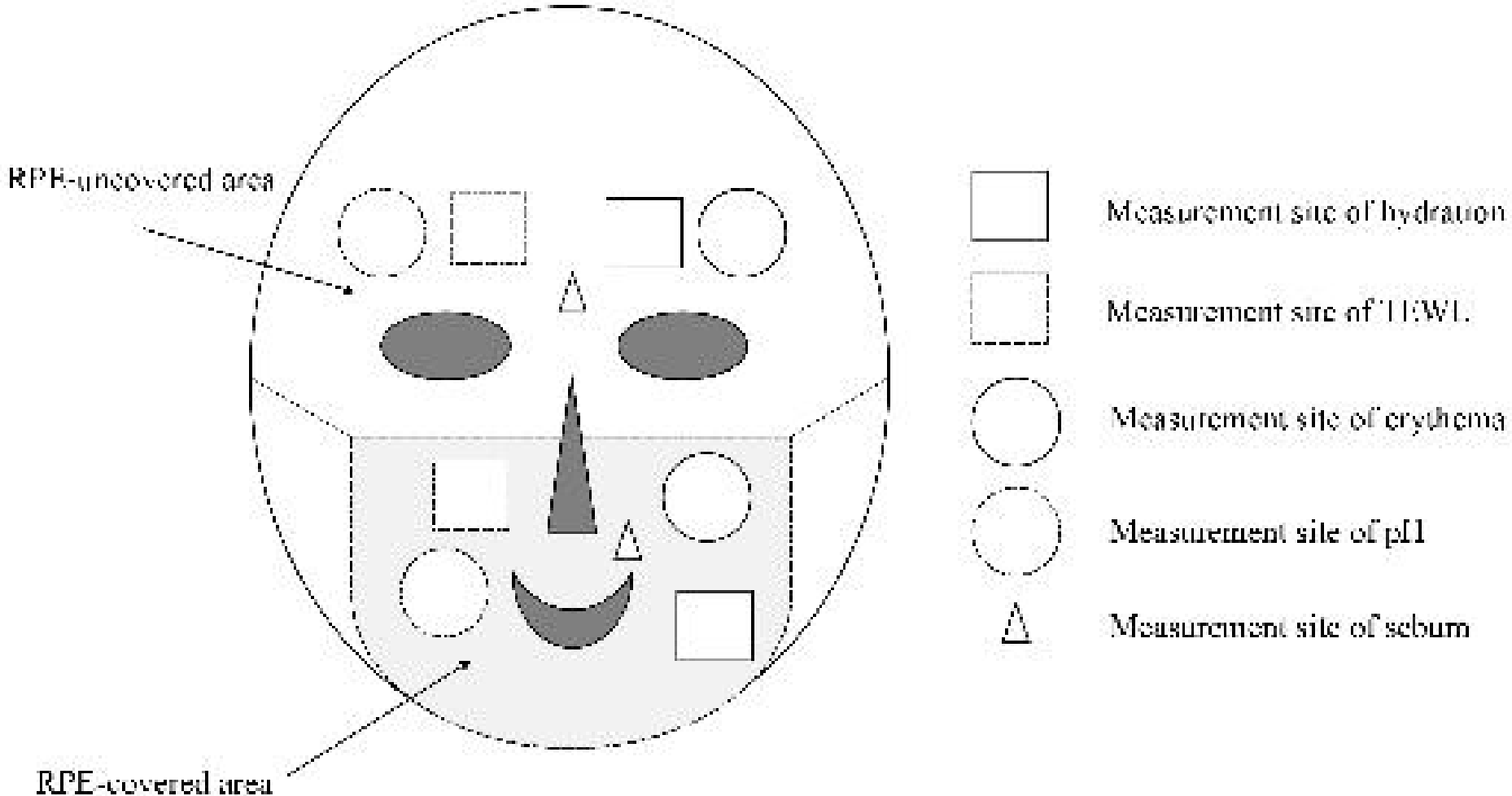
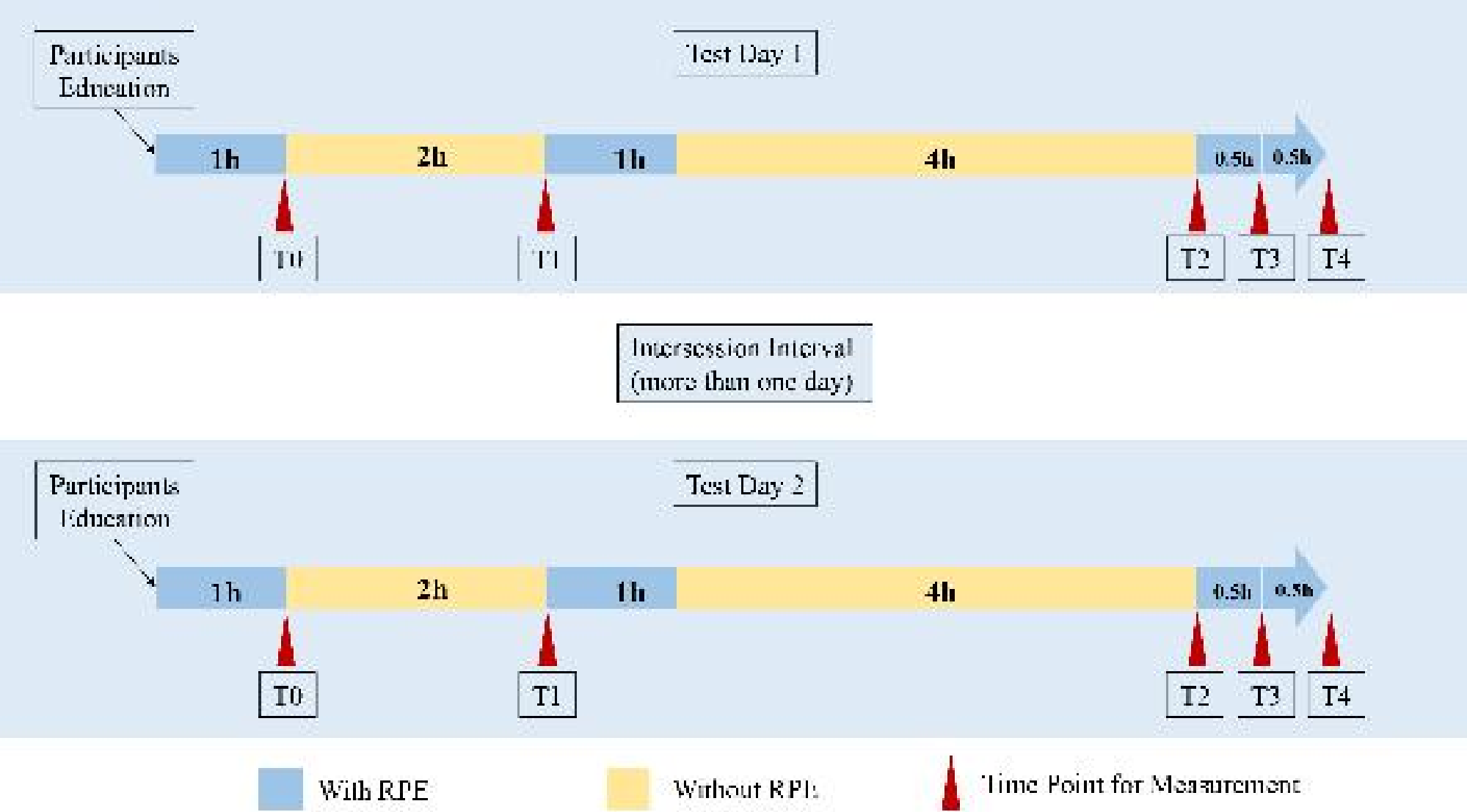

RPE-uncovered area
RPE-covered area
Measurement site of hydration
Measurement site of TEWL
Measurement site of erythema
Measurement site of pH
Measurement site of sebum


Participants Education
Test Day 1
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Participants Education
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T4
With RPE
Without RPE
Time Point for Measurement