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Season- and facial site-specific skin changes due to long-term mask wearing during the COVID-19 pandemic

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Abstract

Background: As people have regularly worn facial masks due to the coronavirus disease 2019 (COVID-19) pandemic, mask-wear-related adverse effects on the skin have been recognized. The aim of this study was to explore skin changes, their seasonal variations in the general population caused by commonly used masks and a possible mechanism underlying negative effects of mask-wearing.

Materials and methods: Eighteen Japanese females participated in the study during summer and winter in Japan. Skin characteristics were measured in the non-mask-wearing preauricular area and the mask-wearing cheek and perioral areas.

Results: Trans-epidermal water loss (TEWL) on the cheek area tended to be increased in winter, which was positively correlated with skin scaliness on the same area. Ceramide (CER) content and composition in the mask-covered stratum corneum (SC) were slightly changed between summer and winter, and CER [NP]/[NS] ratio was negatively correlated with the TEWL on the perioral skin in winter. Skin hydration and sebum secretion were higher on the cheek compared to the perioral area in summer. Skin redness was particularly high on the cheek in winter.

Conclusion: Mask-wear-related skin changes were season- and facial site-specific, and alterations in SC CER may play a role in barrier-related skin problems caused by mask use.

KEYWORDS
ceramides, COVID-19, facial mask, seasonal changes, skin characteristics

1 | INTRODUCTION

Since the World Health Organization declared the COVID-19 (coronavirus disease 2019) pandemic on March 11, 2020, facial-mask-wear has been recommended in many countries and has become a necessity in our daily life. At this time, the beginning of 2022, wearing a mask is still important to prevent infectious disease transmission, and the mandatory use of a facial mask is globally implemented for all individuals, including non-healthcare workers. In-line with this, there is an increasing perception that facial-mask-wear can cause adverse effects on the skin.[1–5]

To date, several studies have reported various adverse skin reactions to masks during the ongoing COVID-19 pandemic. For instance,

Abbreviations: CER, ceramide; COVID-19, coronavirus disease 2019; DEGS2, sphingolipid C4 hydroxylase; KF, Korea Filter; RP–LC–MS, reverse phase–liquid chromatography–mass spectrometry; SC, stratum corneum; TEWL, trans-epidermal water loss.

Tomomi Nakamura and Hiroyuki Yoshida contributed equally to this report and are the co-first authors.

TABLE 1 Types of facial masks usually worn by subjects

	Disposable non-woven mask	Reusable cotton mask	Polyurethane mask	Others
Summer (August 2021)	18	0	0	0
Winter (March 2021)	17	1	1	1

Note: In the winter study, two subjects used disposable non-woven masks and reusable cotton masks, and disposable non-woven masks and polyurethane masks.

a short-term KF94 (Korea Filter 94) mask-wear for 1 or 6 h was found to increase skin temperature, trans-epidermal water loss (TEWL), skin redness and sebum secretion in the mask-wearing region, including the cheek and perioral area of healthy Korean subjects.[6,7] Alternatively, skin hydration on the perioral area was decreased after 1 and 6 h of wearing KF94 masks.[6] In addition, skin elasticity was reduced by using KF94 masks for 6 h a day for 2 weeks, whereas the number of acne lesions and pore volume increased.[7] Another study reported that after wearing KF94 masks at least 6 h a day for 4 weeks, skin wrinkles in the nasolabial folds and pores in the cheek were increased in healthy Korean subjects.[8] More recently, from June 2020 (3 months after the declaration of the COVID-19 pandemic) to December 2020, effects of wearing facial masks (KF94, KF80, KF-anti-droplet and surgical masks) for a period of 6 months on the skin were examined in healthy Korean subjects, and it was reported that TEWL, skin pore area and skin redness on the cheek and/or perioral areas were increased, and skin hydration and elasticity on the cheek and perioral areas were decreased.[9] Collectively, various physiological side effects caused by short- and long-term wearing of facial masks have been identified so far. However, it should be noted that KN94 masks mainly used in those studies are recommended only to healthcare workers, and thus no studies, to our knowledge, have examined skin changes in the general population caused by more commonly used masks. In addition, there is a lack of research on changes in skin characteristics under different weather conditions, for example, in summer and winter, and the mechanism underlying the negative effects caused by wearing facial masks.

In this study, we investigated mask-wear-related skin changes in healthy Japanese females (non-healthcare workers) in the summer and winter conditions of Japan. To examine skin changes by actual use of masks on daily routine, the types of masks that the subjects usually wore were not controlled in this study. We also performed detailed analysis of stratum corneum (SC) lipids to understand the underlying mechanism of skin changes caused by mask-wearing. Our data provide evidence that mask-wear-related changes in skin characteristics were season- and facial site-specific, and that changes in ceramides (CERs) may play a role in the barrier-related skin problems caused by mask use.

2 | MATERIALS AND METHODS

2.1 | Study subjects and environment

Eighteen healthy Japanese female subjects in their 20 s ($n = 6$), 30 s ($n = 6$), 40 s ($n = 2$) and 50 s ($n = 4$) were recruited for the study. All subjects were office workers, and their average daily mask-wearing time has been at least 4 h a day since April 7 in 2020 (the first official declaration of emergency in Japan) except during mealtimes and when asleep. The types of masks usually worn are summarized in Table 1. Due to the state of emergency in Japan in February (midwinter) and the beginning of August (midsummer), skin measurements were conducted during the following two periods: March 15–16 and August 31 to September 2 in 2021. According to the Japan Meteorological Agency (https://www.jma.go.jp/jma/indexe.html), the local average, maximum and minimum temperature were 10.6, 17.7 and 3.7°C on March 15, and 27.4, 30.6 and 24.3°C on August 31, and the humidity was 38% on March 15 and 71% on August 31. Thus, winter and summer conditions were still maintained in the first and second periods, respectively. The study was approved by the Institutional Review Boards of Kao Corporation (Tokyo, Japan), and informed consent was obtained from all subjects before the study. Before skin measurements, the subjects cleaned their faces and acclimated for 15 min in a room with constant humidity (50%) and temperature (20°C). The areas measured for skin characteristics are shown in Figure 1. The preauricular area was included in the non-mask-wearing region, and the cheek and perioral areas were included in the mask-wearing region.

2.2 | Measurement of TEWL

TEWL was measured in duplicate on the preauricular, cheek and perioral areas for each subject using a Tewameter TM300 (Courage & Khazaka, Cologne, Germany).

2.3 | Measurement of skin hydration

Skin hydration was determined in quintuplicate on the preauricular, cheek and perioral areas for each subject using a Corneometer CM825 (Courage & Khazaka, Cologne, Germany).

2.4 | Measurement of sebum content

Sebum content was measured at 1 h after facial wash on the preauricular, cheek and perioral areas using a Sebumeter SM815 (Courage & Khazaka, Cologne, Germany).

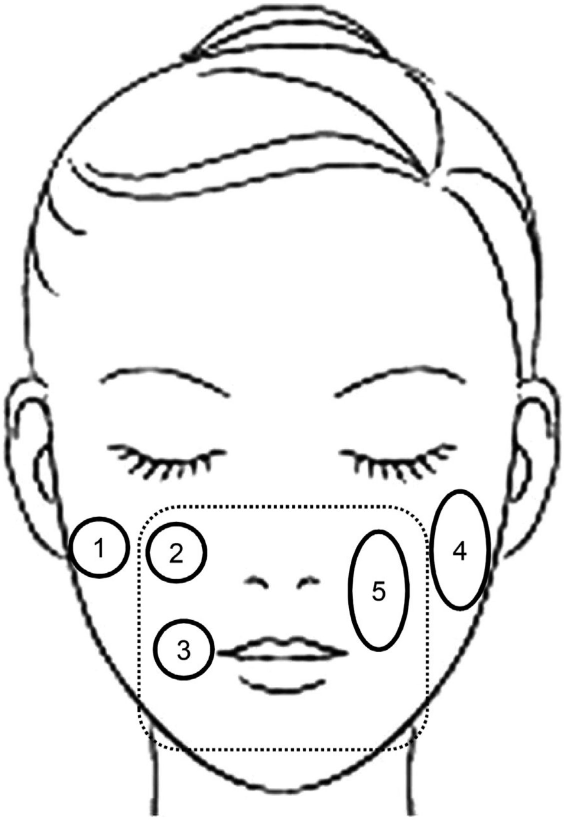

FIGURE 1 Schematic of the areas measured for skin characteristics. Non-mask-wearing region: 1, 4 (preauricular area); mask-wearing region: 2 (cheek area), 3 (perioral area), 5 (cheek and perioral area); trans-epidermal water loss (TEWL), skin hydration, sebum content, skin redness and skin roughness: 1, 2, 3; lipid analysis: 4, 5. The box depicted with dotted line indicates the area covered with a facial mask.

2.5 | Measurement of skin redness

Skin redness was measured in triplicate on the preauricular, cheek and perioral areas for each subject using a spectrophotometer CM-2600d (Konica Minolta Sensing Inc, Tokyo, Japan).

2.6 | Measurement of skin surface roughness

The active state image of skin was obtained in triplicate on the preauricular, cheek and perioral areas for each subject using a Visioscan VC98, and the parameter for skin scaliness (SEsc value) was determined by a software SELS 2000 (Canfield Scientific, Fairfield, NJ, USA). Facial images were taken using a VISIA-Evolution (Canfield Scientific, Fairfield, NJ, USA).

2.7 | Lipid analysis of tape-stripped SC samples

SC samples were collected from the non-mask-wearing preauricular area and the mask-wearing cheek and perioral area (Figure 1) of each subject, followed by the profiling of CERs with using reverse phase–liquid chromatography–mass spectrometry as described previously.[10] Briefly, SC samples were collected by tape-stripping method with three consecutive strippings at the same region using 25 mm × 30 mm square pieces of an adhesive acrylic film tape (465#40; Teraoka Seisakusho, Tokyo, Japan). Lipids were extracted from one-half of each sample by methanol and were dried, then redissolved in methanol/2-propanol/chloroform (9:9:2 v/v/v). Types of CER were analyzed with an Agilent 6130 Series LC/MSD SL system equipped with a multi-ion source, ChemStation software, an Agilent 1260 Infinity Series LC (Agilent Technologies, Santa Clara, CA). *N*-heptadecanoyl-D-erythro-sphingosine (Avanti Polar Lipids, Alabaster, AL, USA) was used as an internal standard. Chromatographic separation of the lipids was performed with an L-column ODS (2.1 × 150 mm, particle size 5 μm, Chemicals Evaluation and Research Institute, Tokyo, Japan), at a flow rate of 0.2 ml/min using a binary gradient solvent system of mobile phase A (water/methanol (1:1, v/v) containing 50-mM ammonium hydrogen carbonate) and mobile phase B (2-propanol). The mobile phases were consecutively programmed as follows: an isocratic elution of A (90%) and B (10%) for 2 min; a linear gradient of A (90%–30%) and B (10%–70%) between 2 and 5 min; a linear gradient of A (30%–0%) and B (70%–100%) between 5 and 35 min; an isocratic elution of A (0%) and B (100%) for 5 min; and an isocratic elution of A (90%) and B (10%) for 10 min to initial condition. The sample injection volume was 10 μl. The column temperature was maintained at 40°C. MS parameters were as follows: polarity, negative ion mode; flow of heated dry nitrogen gas, 4.0 L/min; nebulizer gas pressure, 60 psi; heater temperature of nitrogen gas, 350°C; vaporizer temperature, 200°C; capillary voltage, 4000 V; charging voltage, 2000 V; fragmentor voltage, 200 V. Each type of CER was detected by selected ion monitoring as *m/z* [M−H]−. Soluble proteins were evaluated from the residues after lipid extraction with 0.1-M NaOH and 1% (w/v) sodium dodecyl sulfate in aqueous solution at 60°C for 2 h, then were subsequently neutralized with 2-M HCl. The quantity of protein was determined using a BCA kit (Thermo Scientific, Rockford, IL, USA). The amount of each CER subclass was adjusted per quantitated protein value. The ratio of each CER subclass (ng/μg protein) to CER subclass (ng/μg protein) in SC obtained by tape-stripping was calculated.

2.8 | Statistics

Statistical significance was assessed by paired Student's *t* test and correlations were examined by Pearson's correlation coefficient analysis using Microsoft Excel software (Office 365) (Redmond, WA, USA) or IBM SPSS Statistics 25.0 (IBM, Armonk, NY, USA). A probability of $p < 0.05$ was considered significant.

3 | RESULTS

3.1 | Increase in TEWL on the mask-covered cheek area in the winter, and a positive correlation between TEWL and skin scaliness

We evaluated TEWL, a skin barrier-related indicator, on the non-mask-wearing preauricular area and the mask-wearing cheek and perioral

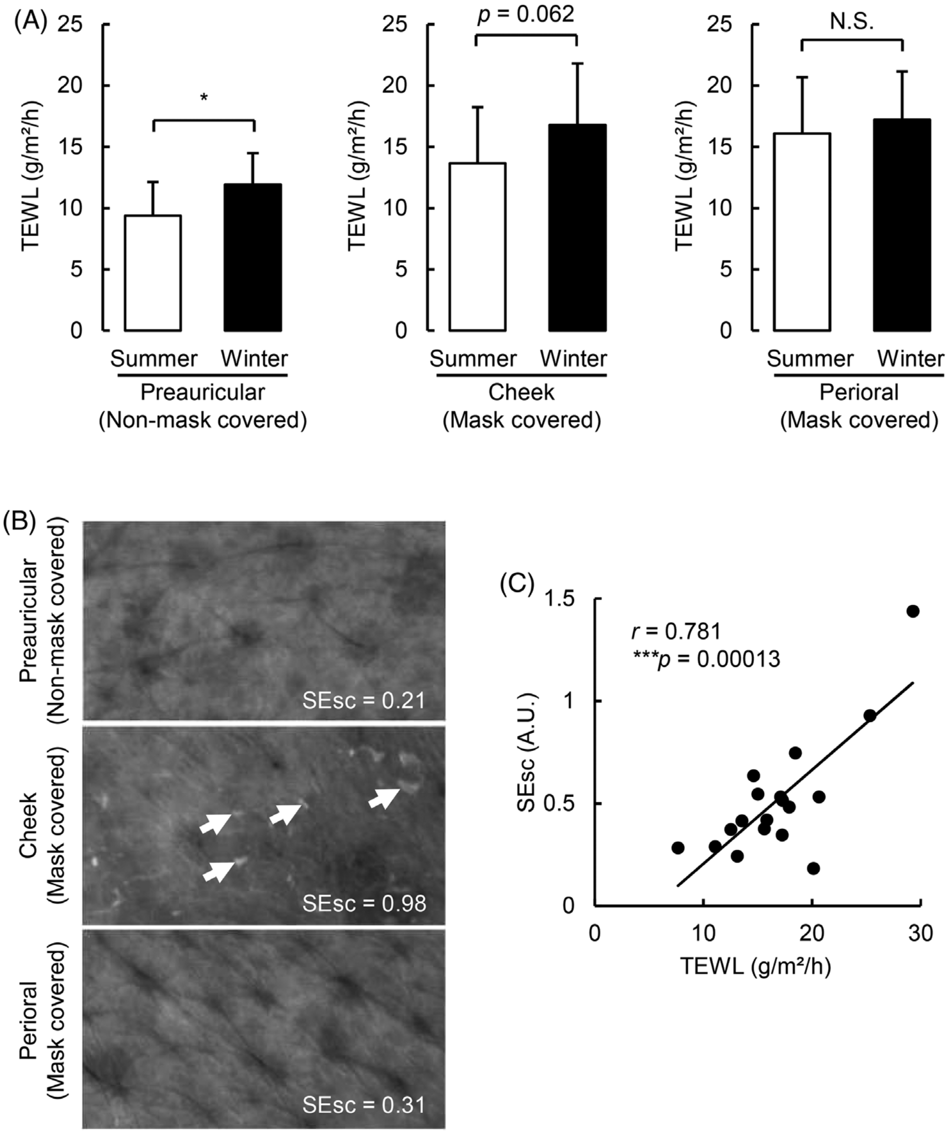

FIGURE 2 Trans-epidermal water loss (TEWL) in non-mask-wearing preauricular area and mask-wearing cheek and perioral areas in the summer and winter, and correlation of TEWL with skin scaliness. (A) TEWL values in the non-mask-wearing preauricular area and the mask-wearing cheek and perioral areas in the summer and winter. Levels of TEWL were measured by a Tewameter. Values are expressed as means ± SD ($n = 18$) and shown as g/m^2/h. Paired Student's *t* test was used for statistical analysis. *$p < 0.05$. N.S., not significant. (B) Representative images of skin scaliness from the preauricular, cheek and perioral areas in the winter. Levels of skin scaliness (SEsc) were determined by Visioscan and software SELS 2000. Arrows indicate scaling areas. (C) Correlation between TEWL and SEsc values in the cheek area in the winter. Correlation was examined by Pearson's correlation coefficient analysis. r = correlation coefficient; ***$p < 0.001$

areas of the same individuals in the summer and winter. As shown in Figure 2A, although there was no significant difference in TEWL on the perioral area between the summer and winter, TEWL on the preauricular area was significantly increased (1.27-fold), and TEWL on the cheek tended to be higher (1.23-fold) in the winter than those in the summer, respectively. These results suggest that the barrier functions of the preauricular and cheek areas are likely to be affected by the winter climate. In addition, we noticed that the subjects had visible rough and scaly skin in mask-wearing cheek in the winter (Figure 2B) and showed that there is a significant positive correlation between TEWL and SEsc (an index of scaliness of skin) values on the cheek in the winter (Figure 2C). These results indicate that the skin barrier function of the cheek area was slightly impaired due to long-term mask wearing in the winter, and the impairment of skin barrier function was associated with scaliness on the cheek.

3.2 | Negative correlations of TEWL with the ceramide content and ceramide [NP]/[NS] ratio in SC of the mask-covered region

To ascertain the basis for the impaired barrier function due to the mask-wearing, we investigated SC lipids, which are largely responsible for the skin barrier function, in the non-mask-wearing preauricular and

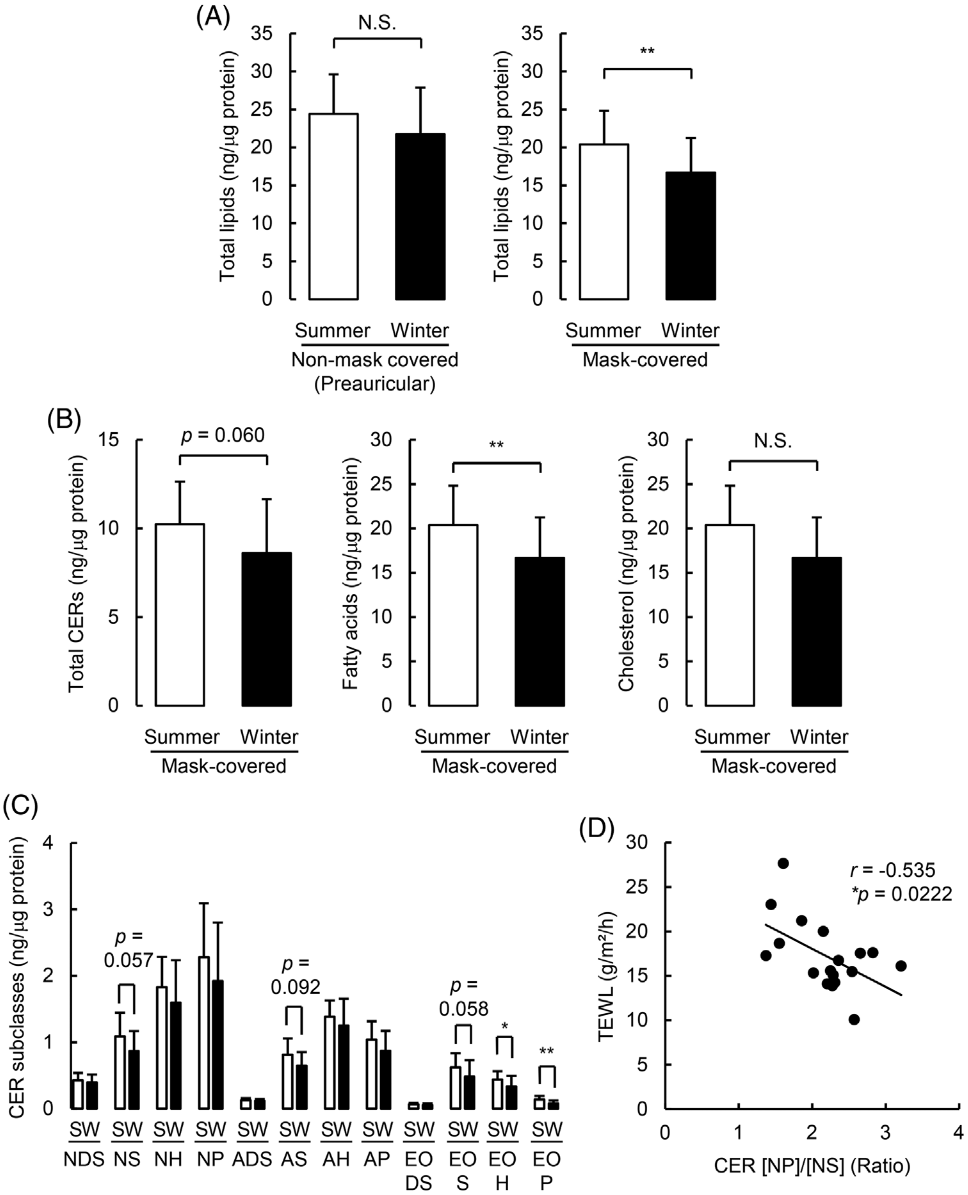

FIGURE 3 Stratum corneum (SC) lipids in non-mask-wearing and mask-wearing regions in the summer and winter, and correlation of ceramide (CER) [NP]/[NS] ratio with trans-epidermal water loss (TEWL). (A–C) The content of total lipids (A), total CERs, fatty acids and cholesterol (B), and CER subclasses (C) in tape-stripped SC from the non-mask-wearing and mask-wearing regions in the summer (S) and winter (W). Levels of SC lipids were measured by reverse phase–liquid chromatography–mass spectrometry (RP–LC–MS) analysis. Values are expressed as means ± SD ($n = 18$) and shown as ng/µg protein. Paired Student's *t* test was used for statistical analysis. $^*p < 0.05$; $^{**}p < 0.01$. N.S., not significant. (D) Correlation between CER [NP]/[NS] ratio and TEWL values in the perioral area in the winter. Correlation was examined by Pearson's correlation coefficient analysis. r = correlation coefficient. $^*p < 0.05$. CER [NDS] contains non-OH fatty acids [N] and dihydrosphingosines [DS], CER [NS] contains [N] and sphingosines [S], CER [NH] contains [N] and 6-hydroxy sphingosines [H], CER [NP] contains [N] and phytosphingosines [P], CER [ADS] contains α-OH fatty acids [A] and [DS], CER [AS] contains [A] and [S], CER [AH] contains [A] and [H], CER [AP] contains [A] and [P], CER [EOS] contains ester-linked fatty acids, ω-OH fatty acids [EO] and [S]. CER [EOH] contains [EO] and [H], and CER [EOP] contains [EO] and [P].

the mask-wearing cheek and perioral regions. As shown in Figure 3A, the total lipid content in the non-mask-wearing region was not significantly changed between the summer and winter, whereas it was significantly decreased in the mask-wearing region in the winter (0.82-fold), compared to that in summer. Among the major constituents of SC lipids, that is, CERs, fatty acids and cholesterol, the content of fatty acids was significantly decreased (0.82-fold) and the content of total CERs tended to be decreased (0.84-fold) in the mask-wearing region in the winter, compared to those in the summer (Figure 3B), respectively. We further assessed the content of 12 CER subclasses and showed that the content of CER [EOH] (CERs containing ester-linked fatty acids, ω-hydroxy fatty acids and 6-hydroxysphingosines) and CER [EOP] (CERs containing ester-linked fatty acids, ω-hydroxy fatty acids and phytosphingosines) was significantly decreased (0.76- and 0.57-fold,

TABLE 2 Correlations of total ceramide (CER) content and CER [NP]/[NS] ratio with trans-epidermal water loss (TEWL) values on the cheek and perioral areas in the summer and winter

		TEWL (g/m²/h) (cheek area)		TEWL (g/m²/h) (perioral area)	
		r	*p*	*r*	*p*
Summer	Total CERs (ng/μg protein)	−0.0435	0.864	−0.416	0.0862
	CER [NP]/[NS] (Ratio)	−0.149	0.555	0.00853	0.973
Winter	Total CERs (ng/μg protein)	−0.254	0.310	−0.405	0.0953
	CER [NP]/[NS] (Ratio)	−0.453	0.0589	−0.535	0.0222*

Abbreviations: CER, ceramide; TEWL, trans-epidermal water loss.

Note: Levels of CER and CER subclasses in the tape-stripped SC samples and TEWL values were measured by reverse phase–liquid chromatography–mass spectrometry (RP–LC–MS) analysis and Tewameter, respectively ($n = 18$). Pearson's correlation coefficient analysis. *r*, correlation coefficient.

*$p < 0.05$.

respectively), and CER [NS] (CERs containing non-hydroxy fatty acids and sphingosines), CER [AS] (CERs containing α-hydroxy fatty acids and sphingosines) and CER [EOS] (CERs containing ester-linked fatty acids, ω-hydroxy fatty acids and sphingosines) tended to be decreased (0.80-, 0.81- and 0.77-fold, respectively) in the mask-wearing area in the winter compared to those in the summer (Figure 3C). Correlation analyses revealed that the total CER level shows a tendency for negative correlations with TEWL values on the perioral area in both summer and winter, and CER [NP] (CERs containing non-hydroxy fatty acids and phytosphingosines)/[NS] ratio, a potential marker of skin barrier function,[11] tends to negatively correlate with TEWL on the cheek and significantly correlates with that on the perioral area the in winter (Table 2 and Figure 3D). These results suggest that the CER content and composition in the mask-wearing region were slightly altered between the summer and winter, and the total CERs and CER [NP]/[NS] ratio may, at least in part, play a role in the impaired barrier function of the mask-wearing region in the both seasons.

3.3 | High skin hydration and sebum secretion of the mask-covered cheek in the summer, whereas low skin hydration of the mask-covered perioral area in the summer and winter

We then examined the skin hydration on the preauricular, cheek and perioral areas in the summer and winter. As shown in Figure 4A, the skin hydration on the preauricular and cheek was not significantly changed between the summer and winter, but the skin hydration on the perioral area tended to be decreased (0.88-fold) in the winter compared to that in the summer. In addition, the skin hydration on the perioral area was significantly lower compared to that on the cheek area in the summer (0.64-fold) and winter (0.61-fold), respectively (Figure 4B). We further measured the sebum secretion after facial wash on the preauricular, cheek and perioral areas in the summer and winter, and showed that the sebum content on the cheek is significantly increased in the summer (3.05-fold) (Figure 5A), and it was significantly higher than that on the perioral area (Figure 5B). These results suggest that long-term mask wearing differently affects skin moisture and sebum secretion depending on the facial site in the summer and winter, that is, the cheek skin is moisturized and sebum-rich in the summer, whereas the perioral skin is dry in the winter.

3.4 | Increase in the skin redness on the non-mask-covered and mask-covered regions in the winter

We then assessed the skin redness (a^* value) on the preauricular, cheek and perioral areas in the summer and winter. As shown in Figure 6A, the a^* values on the preauricular, cheek and perioral areas were significantly increased in the winter (1.39-, 1.40- and 1.39-fold, respectively), compared to the corresponding values in the summer. In addition, the a^* values on the cheek were significantly higher in both the summer and winter (1.21- and 1.23-fold, respectively), compared to that on the perioral area (Figure 6B). Figure 6C presents a participant's facial skin image showing skin redness on the cheek in the winter. These results suggest that regardless of whether the skin is covered with a mask, the facial skin redness, an indicator of inflammation, is increased under dry and cold climatic conditions in the winter, and long-term mask wearing may aggravate skin inflammation, particularly on the cheek skin.

4 | DISCUSSION

In the present study, we demonstrated that the skin barrier function tends to be disrupted in the mask-covered cheek area in the winter, which may attribute to scaly cheek skin. The changes in SC CER levels and composition were related to impaired barrier function. In addition, changes in skin hydration, sebum secretion and skin redness were season- and/or facial site-dependent.

Previous studies reported that skin barrier function is disrupted in healthcare workers after wearing protective masks,[12] and a 6-month period of mask use weakened skin barrier function in healthy Korean subjects.[9] In the present study, we disclosed that TEWL in the mask-covered cheek area tends to be increased in the winter compared to that in the summer in the Japanese females. Mask microclimates (the temperature and humidity inside the mask) are hot and humid due to the occlusive effect of facial masks, and prolonged occlusion is known

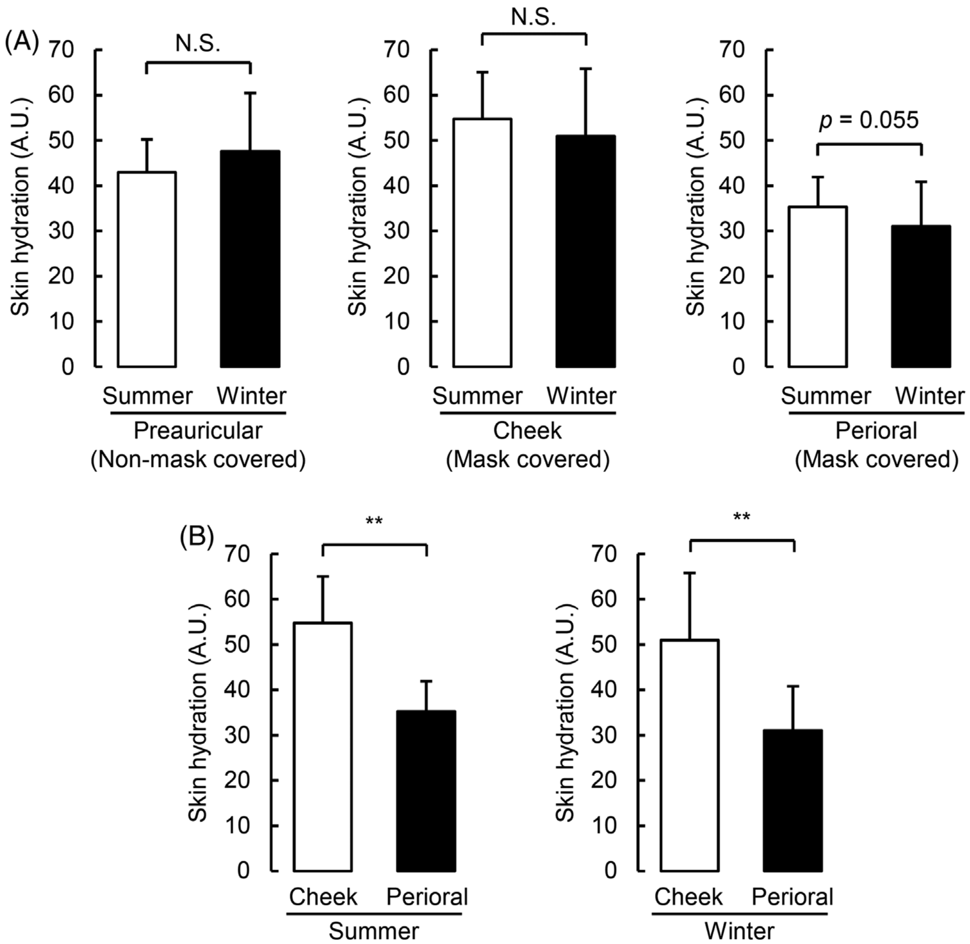

FIGURE 4 Skin hydration in non-mask-wearing preauricular area and mask-wearing cheek and perioral areas in the summer and winter. (A and B) Skin hydration values in the non-mask-wearing preauricular area and the mask-wearing cheek and perioral areas in the summer and winter. Levels of skin hydration were measured by a Corneometer. Values are expressed as means ± SD ($n = 18$) and shown as A.U. Paired Student's *t* test was used for statistical analysis. $^{**}p < 0.01$. N.S., not significant

to induce skin barrier damage.[13] Notably, atmospheric temperature and humidity were considerably different in the summer and winter conditions in Japan, and thus the skin inside the mask in the winter may be repeatedly exposed to the high temperature and humidity due to exhalation (under the facial mask occlusion) and the low atmospheric temperature and humidity (without facial mask), which may result in the increased TEWL. We also showed that TEWL values are positively correlated with SEsc values on the cheek in the winter. Previously, scratching and friction on human skin simultaneously increased TEWL and SEsc values compared to baseline measurements.[14] Thus, one can speculate that the cheek skin is frequently in direct contact with face masks, and the friction created between facial masks and cheek skin may contribute to the altered barrier function and skin scaliness.

One of the interesting findings of this study was that SC CER levels and composition in the mask-covered region were altered between the summer and winter conditions, and CER [NP]/[NS] ratio was negatively correlated with TEWL values on the cheek and perioral areas in the winter. CERs represent the major lipid species of lamellar sheets present in the intercellular spaces of SC and have diverse molecular structures that comprise 12 subclasses in human SC.[15,16] Previously, an altered CER composition in SC, such as an increased CER [AS] and a decreased CER [NP], was reported in some proinflammatory diseases, including atopic dermatitis and psoriasis.[17–19] More recently, CER [NP]/[NS] ratio was found to be a sensitive marker related to skin properties, including SC barrier function in healthy subjects and the differentiation of cultured human skin keratinocytes, that is, CER [NP]/[NS] ratio was negatively correlated with TEWL values in healthy skin and increased during differentiation of cultured keratinocytes.[11] In addition, sphingolipid C4 hydroxylase (DEGS2), a key regulator which is involved in the biosynthesis of CER [NP] through the C4-hydroxylation of CER [NDS] (CERs containing non-hydroxy fatty acids and dihydrosphingosines), is known to be upregulated during keratinocyte differentiation.[20] Therefore, although further investigation is needed to determine which factors contribute to the changes in CERs, the cheek skin in the winter may be under undifferentiated conditions leading to impaired CER [NP] biosynthesis, which may in turn result in altered CER composition and barrier disturbance of the cheek skin.

Consistent with the previous findings,[9] we showed that skin hydration on the mask-covered perioral area is significantly lower than that on the mask-covered cheek area in the summer and winter and tends

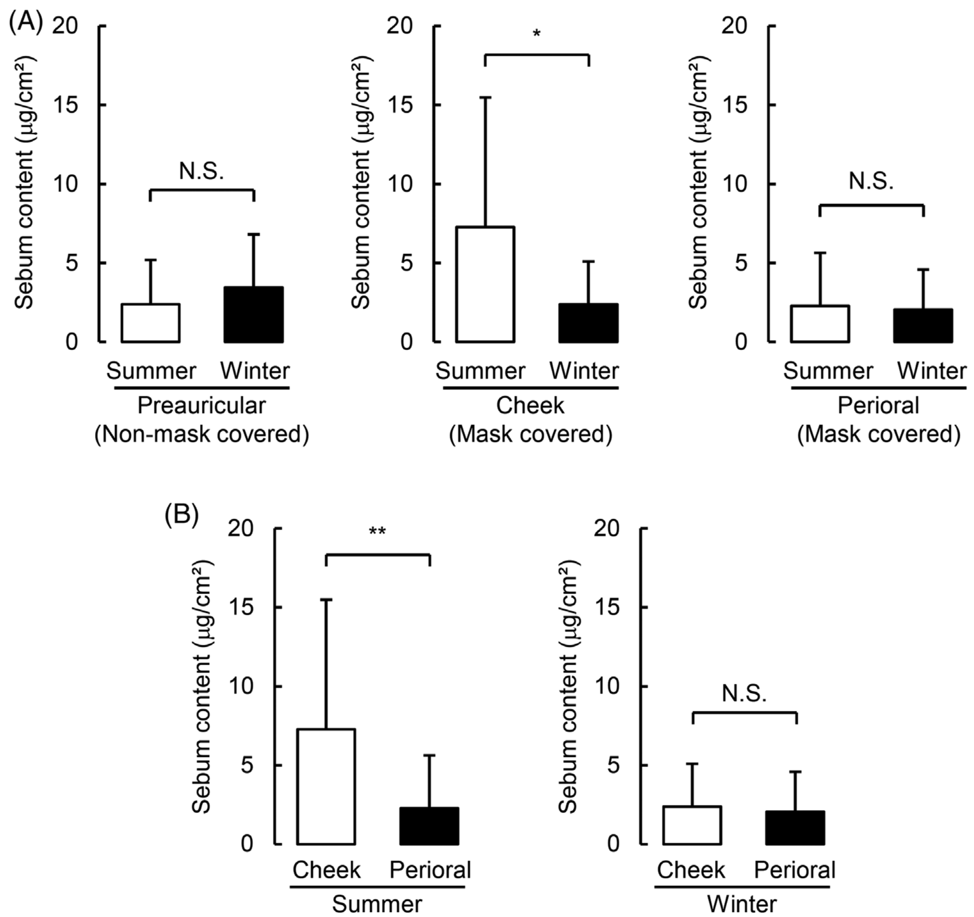

FIGURE 5 Sebum in non-mask-wearing preauricular area and mask-wearing cheek and perioral areas in the summer and winter. (A and B) Sebum content after facial wash in the non-mask-wearing preauricular area and the mask-wearing cheek and perioral areas in the summer and winter. Levels of sebum were measured by a Sebumeter. Values are expressed as means ± SD ($n = 18$) and shown as μg/cm^2. Paired Student's *t* test was used for statistical analysis. *$p < 0.05$; **$p < 0.01$. N.S., not significant

to be reduced in the winter. Because the skin barrier function in the perioral area tended to be negatively correlated with SC CER level and was significantly negatively correlated with a CER [NP]/[NS] ratio, a decline of water retention capacity may be related to the development of mask-wear-related dry skin. Importantly, we found that the sebum secretion after facial wash on the cheek is increased in the summer, and a previous study reported a significant positive correlation between the SC hydration and sebum content.[21] Therefore, although further study is required, it is tempting to speculate that increased sebum secretion may, at least in part, contribute to the skin moisture level on the mask-covered cheek in the summer.

Among the skin characteristics examined, only *a** values in all the measurement sites were higher in the winter compared to those in the summer. Because the *a** value is known to reflect the skin conditions of redness/erythema,[22] the cold and dry winter weather conditions may have caused mild skin erythema on the entire face. In addition, the redness on the mask-covered cheek was higher compared to the mask-covered perioral area, suggesting that mask-wearing exacerbates inflammation on the cheek skin. Likely reasons for the change may be friction and/or pressure due to contact of the cheek skin with the fabric of facial masks. This notion is supported by previous findings that the areas that receive frequent contacts with masks tend to develop skin erythema.[23] A potential limitation of this study was that we obtained the data from the cheek and perioral areas only under facial masks; we did this because use of facial mask was mandatory for all individuals in Japan. Thus, further study to measure skin properties without a mask is warranted. In addition, our study included only 18 Japanese females with the uneven distribution of age groups and was conducted under the Japanese temperate climate. A previous study reported that there are sex-based differences in skin changes, including skin redness and roughness caused by mask use,[7] and skin differences among ethnicities and age groups have been extensively documented.[19,24–27] Therefore, it would be desirable for further larger scale studies to be conducted on males and/or females in different skin types, age groups or ethnic groups under different climate conditions to better understand adverse effects of mask-wearing on the skin.

In conclusion, our study provides new insights into our understanding of season- and facial site-specific adverse skin reactions caused by prolonged wearing of masks during the COVID-19 pandemic. From the viewpoint of the ongoing COVID-19 pandemic and the increasing air pollution problems, it is becoming more important to understand skin changes with mask use. Of note, changes in SC CERs may play a

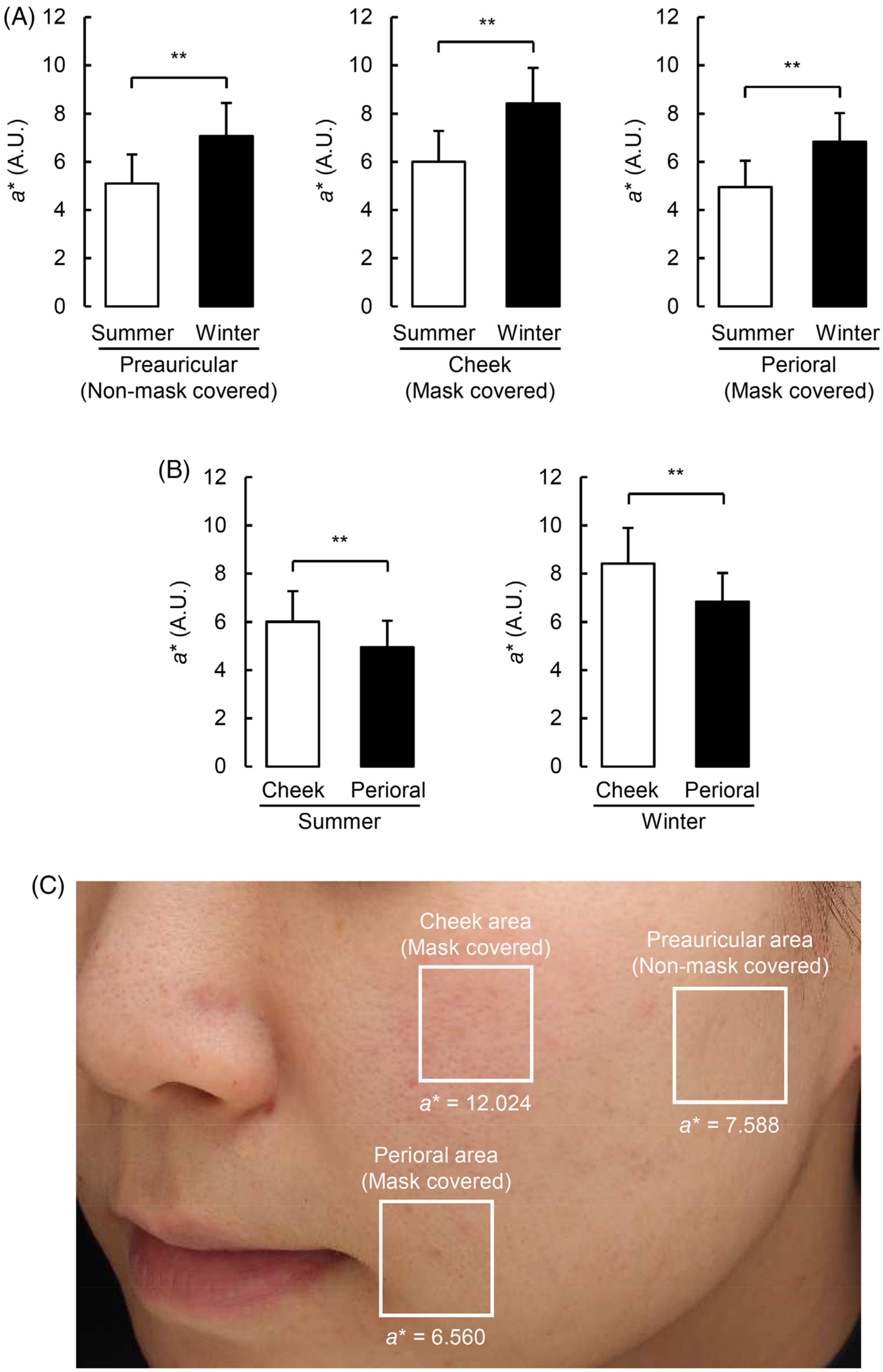

FIGURE 6 Skin redness in non-mask-wearing preauricular area and mask-wearing cheek and perioral areas in the summer and winter. (A and B) Skin redness (*a** values) in the non-mask-wearing preauricular area and the mask-wearing cheek and perioral areas in the summer and winter. Levels of skin redness (*a**) were measured by a spectrophotometer. Values are expressed as means ± SD ($n = 18$) and shown as A.U. Paired Student's *t* test was used for statistical analysis. $^{**}p < 0.01$. (C) Representative image of participant's facial skin showing redness on the cheek skin in the winter. Levels of skin redness (*a**) on the cheek, perioral and preauricular areas were measured by a spectrophotometer.

role in declined epidermal permeability barrier homeostasis and SC integrity in mask-covered skin. Therefore, we propose counteracting the changes in CERs via skin care products would be a promising strategy to prevent or improve barrier-related skin problems caused by mask use.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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