



ORIGINAL ARTICLE

Long-term effects of face masks on skin characteristics during the COVID-19 pandemic

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Abstract

Background: Nowadays, face masks are a crucial part of our daily life. Previous studies on their impact on the skin usually focused on the adverse effects of face masks. Few studies have assessed their influence on skin characteristics. In a previous study, we identified the short-term effects of wearing face masks. Herein, we describe the long-term skin effects of face masks, for a period of 6 months.

Materials and methods: Healthy volunteers (19 men and women), who wore face masks, participated in the study from June 2020 to December 2020. In all participants, skin characteristics such as trans-epidermal water loss (TEWL), skin hydration, skin elasticity, skin pore area, skin keratin amount, skin temperature, skin redness, and skin color were measured three times.

Results: TEWL, skin hydration, skin elasticity, skin pore area, skin keratin amount, and skin color changed significantly after 6 months. TEWL, skin hydration, skin pore area, skin keratin amount, and skin color were significantly different between the mask-wearing and non-mask-wearing areas.

Conclusion: Long-term daily use of face masks can alter skin characteristics. Special care should be focused on the mask-wearing regions.

KEYWORDS

mask-skin zone, trans-epidermal water loss, skin hydration, skin keratin amount, skin pore area, skin elasticity

1 | INTRODUCTION

Since December 2019, the COVID-19 pandemic has continued worldwide. In line with this, it has been almost a year since people wore a mask on a daily routine. Before the pandemic, the use of face masks was usually limited only to people with occupational hazards. However, currently, this is not the case. It is, hence, crucial to further evaluate its effect on the skin. Previous studies have focused on its adverse effects.¹⁻⁴ However, only a few papers have reported the changes in skin characteristics over time.

Previously, we have identified the short-term effect of wearing a mask on the skin.⁵ Herein, we investigated the long-term effects of wearing a mask on the skin for a period of 6 months.

2 | MATERIALS AND METHODS

2.1 | Subjects and environment

Healthy volunteers (19 men and women; mean age = 33.6) participated in this study. They were fully informed about the objectives and details

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TABLE 1 Main type of face mask between June to September and September to June

	Surgical mask	KF-AD mask	KF80 mask	KF94 mask
June to September	16	2	-	1
September to December	13	4	1	3

Abbreviations: KF-AD, Korean filter-anti droplet; KF80, Korean filter 80; KF94, Korean filter 94.

of the study. They voluntarily participated in the study and provided written informed consent. The study was in accordance with the Declaration of Helsinki.

The skin parameters identified were 1. skin temperature, 2. skin redness, 3. skin pore area, 4. trans-epidermal water loss (TEWL), 5. skin hydration, 6. skin elasticity, 7. amount of skin keratin, and 8. skin color. These parameters were measured three times from June 2020 to December 2020: 1. June 22 to July 2, 2. September 21–25, 3. December 14–16. These periods included the summer and fall of Korea.

During the measurement period, we determined the type of masks that they used. Four types of masks were used: 1. surgical mask, 2. Korean filter-anti droplet (KF-AD) mask, 3. Korean filter 80 (KF80) mask, and 4. Korean filter 94 (KF94) mask. The types of masks usually worn are summarized in Table 1. The grades and characteristics of each mask are listed in Table 2. As the seasons and external environment changed from summer to fall to the beginning of the winter, the type of mask varied slightly.

All participants were office workers. The average daily mask-wearing time based on the 5 working days per week is listed in Table 3. Depending on the coronavirus situation, the participants worked either at home or in the office. When participants worked at home, they did not wear masks. This explains the decrease in the mask-wearing time of the week.

Before measurements, participants washed their faces and stayed in a controlled room with a room temperature of $22 \pm 2^\circ\text{C}$ and relative humidity of $50 \pm 5\%$ to stabilize the skin. The areas measured for each skin characteristic are shown in Figure 1. Mask-wearing regions include

TABLE 3 Daily average mask-wearing time (in hours) during the 5 working days. (A) The average daily mask-wearing time between June and September. (B) The average daily mask-wearing time between September and December

	Daily mask-wearing time (in hours)					
	1–2	2–4	4~6	6~8	8~10	>10
Number of respondents (n) from June to September	-	-	2	7	8	2
Number of respondents (n) from September to December	1	4	2	3	8	1

the cheek, chin, and perioral areas while non-mask-wearing regions include the forehead.

2.2 | Measuring TEWL

TEWL was measured on the forehead, cheeks, perioral area, and chin using a Vapometer (Delfin Technology Ltd, Kuopio, Finland).

2.3 | Measuring skin hydration and skin elasticity

Skin hydration and skin elasticity were determined using Corneometer and Cutometer MPA580 devices (C+K, Köln, Germany), respectively. Skin hydration and skin elasticity measurements were performed on the forehead, cheeks, perioral area, and chin.

2.4 | Measuring skin pore area

Facial images for skin pore analysis were taken using VISIA-CR (CANFIELD, Fairfield, USA). Skin pore analysis was performed on the forehead, cheeks, and perioral area using the cross mode from VISIA-CR.

TABLE 2 Grade and characteristic of masks worn by the participants^{6,7,8}

Health masks	Grade	Standard		
		Dust collection efficiency	Inhalation pressure	Air leakage rate
	KF94 mask	Over 94% (NaCl and paraffin oil test)	Below 70 Pa	Below 11.0%
	KF80 mask	Over 80% (NaCl test)	Below 60 Pa	Below 25.0%
Korean filter-anti droplet (KF-AD) mask	Prevention of droplet infection in daily life			
Surgical mask	Prevention of infection during care or treatment			

Block fine particle: KF94 mask > KF80 mask > KF-AD mask, surgical mask.

Breathing convenience: KF-AD mask, Surgical mask > KF80 mask > KF94 mask.

Abbreviations: KF80, Korean filter 80; KF94, Korean filter 94.

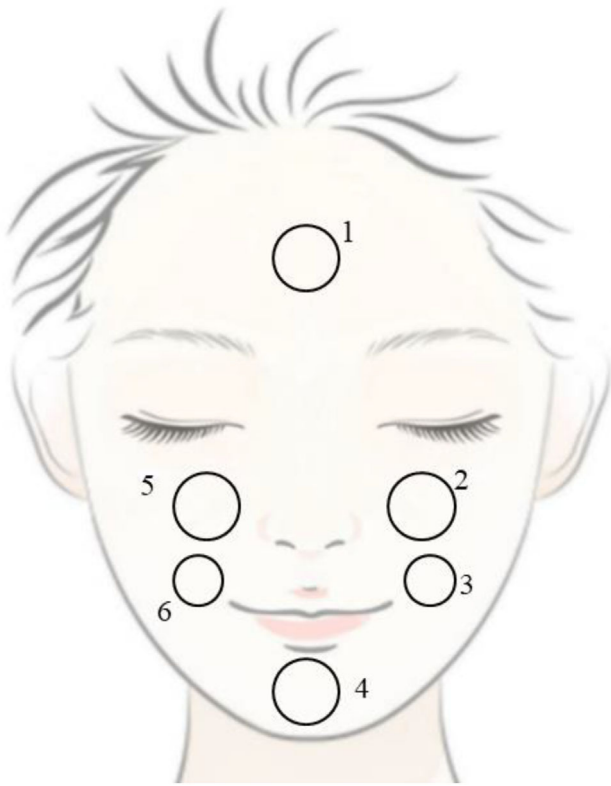


FIGURE 1 Schematic of the measuring areas by skin characteristics. Mask-skin zone (mask-wearing area): 2, 3, 4, 5, 6; non-mask-wearing area: 1; skin temperature: 1, 2, 3, 4; trans-epidermal water loss (TEWL): 1, 4, 5, 6; skin hydration: 1, 2, 3, 4; skin pore: 1, 2, 3; skin redness: 1, 2; skin elasticity: 1, 2, 3, 4; skin keratin amount: 1, 4, 5, 6; skin color: 1, 5

Several filters in Image-Pro 10 software (Media Cybernetics, Silver Spring, USA) were used to emphasize the skin pores in the analysis area. The skin pore area (measured in pixels) was analyzed.

2.5 | Measuring skin keratin amount

Skin keratin was collected using D-Squame Stripping discs (Cuderm Corporation, Dallas, USA) and D-Squame pressure instrument (Cuderm Corporation, Dallas, USA). The amount of keratin on the stripping disc was quantified and analyzed using D-Squame Scan 850A (Cuderm Corporation).

2.6 | Measuring skin temperature and skin redness

Skin temperature was measured on the forehead, cheeks, perioral area, and chin using a thermal imaging camera (FLIR T640, Wilsonville, USA). Facial images were captured using VISIA-CR (CANFIELD, Fairfield, USA). Skin redness was analyzed on the forehead and cheeks using RBX red mode images from VISIA-CR.

2.7 | Measuring skin color

Skin color, lightness (L^*), redness (a^*), and yellowness (b^*) were measured on the forehead and cheeks using a Spectrophotometer CM-2600d (Minolta, Japan).

2.8 | Statistical analysis

Statistical analyses were performed using SPSS Statistics 20 (IBM Corp., Armonk, NY, USA). The changes in skin characteristics from mask-wearing and non-mask-wearing areas were compared by RM-ANOVA. If normality was not satisfied, Friedman and Wilcoxon tests were used. Statistical significance was set at $p < 0.05$.

3 | RESULTS

3.1 | TEWL

From June to December, the TEWL of the mask-skin zone (mask-wearing area) increased. The TEWL of the cheeks and perioral area increased by 48.31% ($p < 0.001$) and 16.67% ($p < 0.05$), respectively. Moreover, the TEWL of the chin increased by 11.51% ($p = 0.47$). On the other hand, the TEWL of the forehead (non-mask-wearing area) slightly increased by 4.84% ($p = 0.528$). TEWL of the mask-wearing areas (cheeks [$p < 0.001$] and perioral areas [$p < 0.05$]) showed significant differences compared to the forehead (Figure 2).

From June to September, the TEWL of the cheeks and perioral area increased by 30.79% ($p < 0.001$) and 17.53% ($p < 0.05$), respectively. The TEWL of the chin increased by 5.53% ($p = 0.322$), while that of the forehead was similar to the result in June. The TEWL of the cheeks ($p < 0.001$) and perioral areas ($p < 0.01$) were significantly different from those of the forehead.

From September to December, the TEWL of the cheeks and chin increased by 13.99% ($p = 0.092$) and 5.67% ($p = 0.113$), respectively. The TEWL of the forehead increased by 5.66% ($p = 0.351$).

3.2 | Skin hydration

From June to December, the mask-skin zone had a decrease in skin hydration. The skin hydration of the perioral area and chin decreased by 19.65% ($p < 0.05$) and 10.90% ($p < 0.05$), respectively. Moreover, the skin hydration of the cheeks decreased by 8.70% ($p = 0.081$). In contrast, the skin hydration of the forehead was similar to the result in June. Compared to the forehead, the skin hydration of the cheeks ($p < 0.05$), perioral area ($p < 0.05$), and chin ($p < 0.05$) were significantly different (Figure 3).

From June to September, the skin hydration of the cheeks, perioral area, and chin decreased by 9.50% ($p = 0.035$), 9.08% ($p = 0.134$), and 3.87% ($p = 0.245$). The skin hydration of the forehead was similar to the result in June.

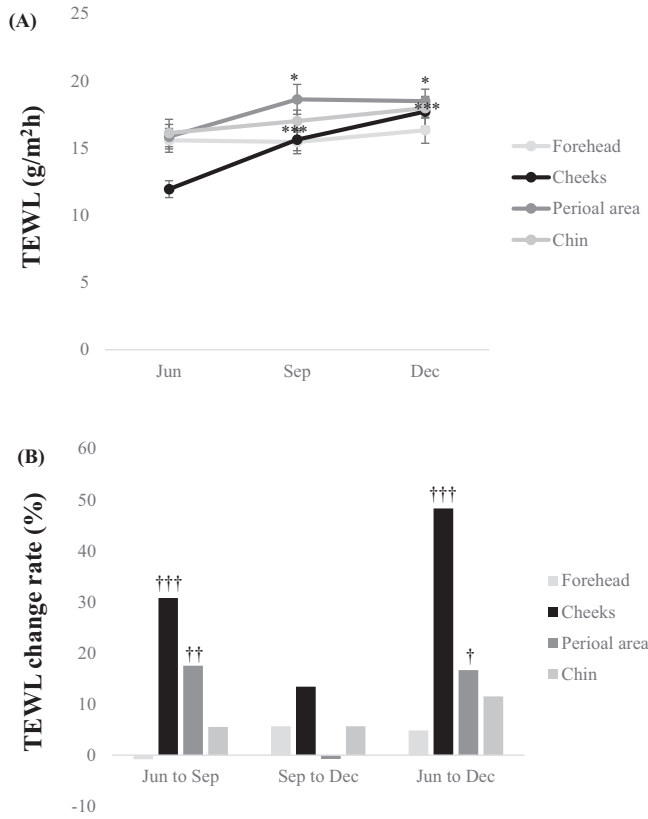


FIGURE 2 Trans-epidermal water loss (TEWL) measurements in June, September, and December. (A) TEWL result of each measurement area. (B) TEWL change rate of each measurement area from June to September, September to December, and June to December

From September to December, the skin hydration of the perioral area and chin decreased by 11.63% ($p < 0.05$) and 7.31% ($p < 0.05$), respectively. The skin hydration of the forehead was similar to the result in June.

3.3 | Skin elasticity (R2)

From June to December, the skin elasticity of the cheeks, perioral area, and chin decreased by 14.54% ($p < 0.001$), 12.94% ($p < 0.001$), and 8.30% ($p < 0.001$), respectively. Meanwhile, the skin elasticity of the forehead decreased by 17.04% ($p < 0.001$) (Figure 4).

From June to September, the skin elasticity of the cheeks and perioral area decreased by 7.75% ($p < 0.001$) and 6.38% ($p < 0.001$), respectively, while that of the chin increased by 2.14% ($p < 0.01$). In contrast, the skin elasticity of the forehead decreased by 8.26% ($p < 0.001$).

From September to December, the skin elasticity of the cheeks, perioral area, and chin decreased by 7.36% ($p < 0.05$), 6.43% ($p < 0.001$), and 10.22% ($p < 0.001$), respectively. Meanwhile, the skin elasticity of the forehead decreased by 9.58% ($p < 0.01$).

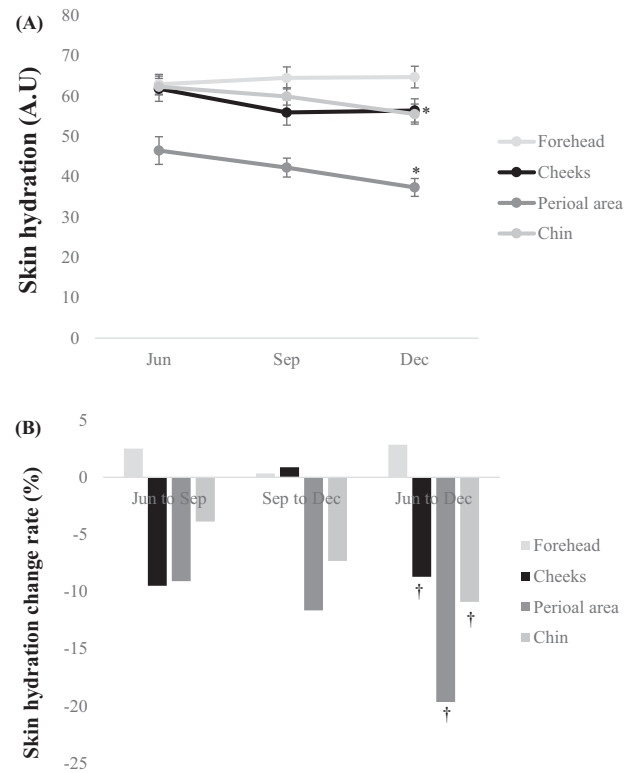


FIGURE 3 Skin hydration measurements in June, September, and December. (A) Skin hydration result of each measurement area. (B) Skin hydration change rate of each measurement area from June to September, September to December, and June to December

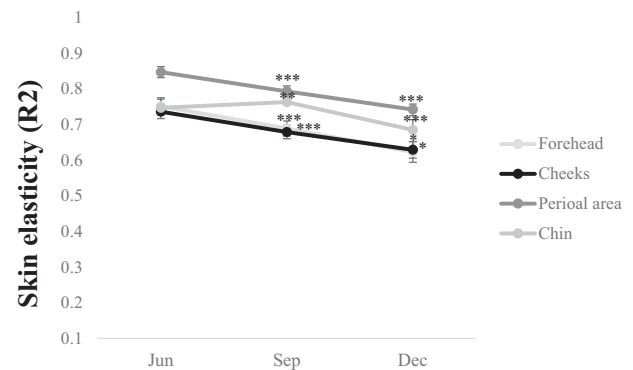


FIGURE 4 Skin elasticity (R2) measurements in June, September, and December. Skin elasticity result of each measurement area. * $p < 0.05$, ** $p < 0.005$, *** $p < 0.001$ September or December versus June

3.4 | Skin pore area (pixel)

From June to December, the skin pore area of the mask-skin zone increased. The skin pore area of the cheeks and perioral area increased by 84.97% ($p < 0.01$) and 98.75% ($p < 0.001$), respectively. Meanwhile, the skin pore area of the forehead increased by 43.58% ($p = 0.808$). Compared to the forehead, the skin pore area of the cheeks was significantly different ($p < 0.01$) (Figure 5).

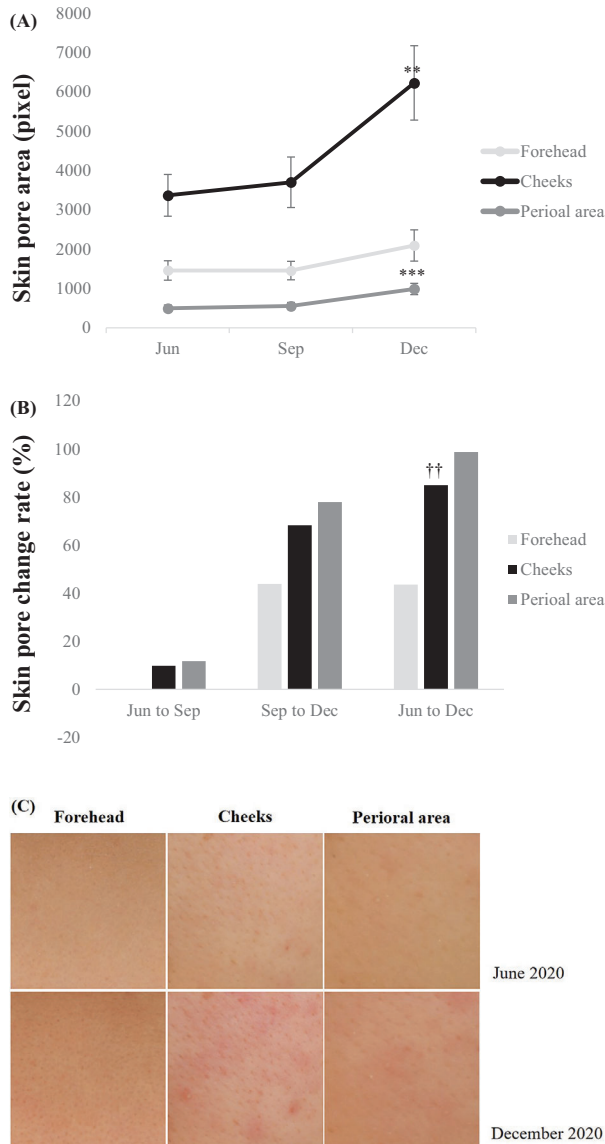


FIGURE 5 Skin pore area measurements in June, September, and December. (A) Skin pore area result of each measurement area. (B) Skin pore area change rate of each measurement area from June to September, September to December, and June to December. (C) Image of the skin pore area variations during the 6-month period

From June to September, the skin pore area of the cheeks and perioral area increased by 9.87% ($p = 0.388$) and 11.73% ($p = 0.597$), respectively. The skin pore areas of the forehead were similar to that in June.

From September to December, the skin pore area of the cheeks and perioral area increased by 68.27% ($p < 0.01$) and 77.89% ($p < 0.01$), respectively. The skin pore area of the forehead increased by 43.80% ($p = 0.104$).

3.5 | Skin keratin levels

From June to December, the amount of skin keratin in the mask-skin zone increased. Skin keratin levels in the cheeks, perioral area, and

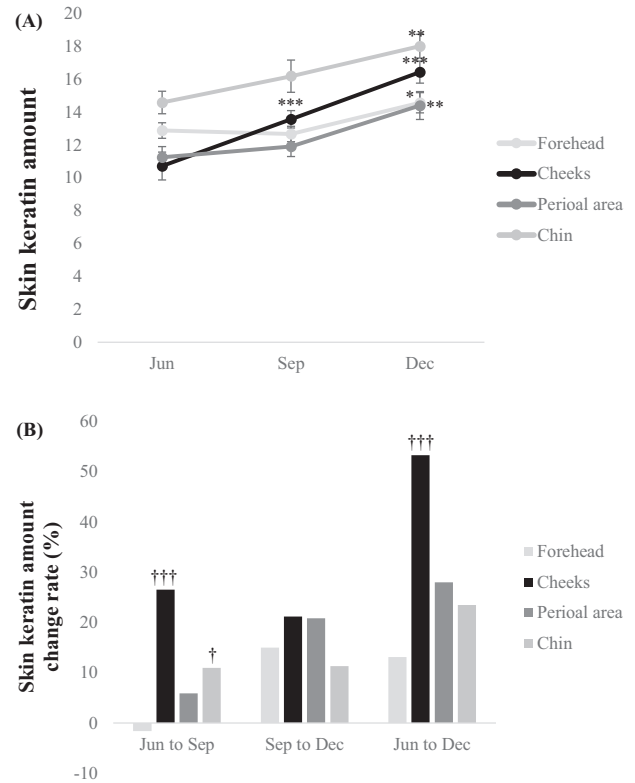


FIGURE 6 Skin keratin amount measurements in June, September, and December. (A) Skin hydration result of each measurement area. (B) Skin keratin amount change rate of each measurement area from June to September, September to December, and June to December

chin increased by 53.29% ($p < 0.001$), 27.99% ($p < 0.01$), and 23.50% ($p < 0.01$), respectively. Meanwhile, skin keratin levels in the forehead increased by 13.12% ($p < 0.05$). Compared to the forehead, the skin keratin levels on the cheeks were significantly different ($p < 0.001$) (Figure 6).

From June to September, skin keratin levels of the cheeks increased by 26.52% ($p < 0.001$). Moreover, the amount of skin keratin in the perioral areas and chin increased by 5.90% ($p = 0.325$) and 10.98% ($p = 0.086$), respectively. Meanwhile, skin keratin levels in the forehead were similar to those in June. Compared to the forehead, the skin keratin levels of the cheeks ($p < 0.001$) and chin ($p < 0.05$) were significantly different.

From September to December, the skin keratin levels of the cheeks and perioral area increased by 21.15% ($p < 0.01$) and 20.86% ($p < 0.05$), respectively. The amount of skin keratin in the chin increased by 11.29% ($p = 0.077$). Skin keratin levels in the forehead increased by 15.00% ($p < 0.05$).

3.6 | Skin temperature

From June to December, the skin temperature of the mask-skin zone significantly increased (1.25–2.35°C). Skin temperatures of the

cheeks, perioral area, and chin increased by 7.33% ($p < 0.001$), 3.71% ($p < 0.001$), and 3.79% ($p < 0.001$), respectively. The skin temperature of the forehead increased by 2.59% ($p < 0.01$). Compared to the forehead, the skin temperature of the cheeks ($p < 0.001$) and perioral areas ($p < 0.05$) were significantly different.

From June to September, the skin temperature of the mask-skin zone significantly increased (0.88–0.72°C). Skin temperatures of the cheeks, perioral area, and chin increased by 5.38% ($p < 0.001$), 2.69% ($p < 0.01$), and 2.63% ($p < 0.01$), respectively. The skin temperature of the forehead increased by 1.58% ($p < 0.01$). Compared to the forehead, the skin temperature of the cheeks was significantly different ($p < 0.001$).

From September to December, the skin temperature of the cheeks increased by 1.86% ($p = 0.03$). The skin temperature of the forehead increased by 1.00% ($p < 0.05$).

3.7 | Skin redness

From June to December, the skin redness of the cheeks increased by 10.27% ($p = 0.065$). On the other hand, the skin redness of the forehead was similar to the result in June. Compared to the forehead, the skin redness of the cheeks was significantly different ($p < 0.05$).

From June to September, the skin redness of cheeks increased by 4.94% ($p = 0.113$).

From September to December, the skin redness of cheeks increased by 5.08% ($p = 0.592$).

3.8 | Skin color

From June to December, skin color changes were variable. For the cheeks, skin redness increased by 13.08% ($p < 0.001$), while skin lightness and yellowness decreased by 1.49% ($p < 0.01$) and 6.99% ($p < 0.05$), respectively. The skin lightness of the forehead was similar to that in June. For the forehead, skin redness increased by 2.52% ($p = 0.632$), while yellowness decreased by 3.71% ($p = 0.082$). Compared to the forehead, the skin lightness ($p < 0.001$) and redness ($p < 0.01$) of the cheeks were significantly different (Figure 7).

From June to September, color changes in the cheeks include a 6.18% ($p < 0.01$) reduction in yellowness and a 3.40% ($p = 0.055$) increase in redness. In the forehead, skin redness and yellowness decreased by 1.98% ($p = 0.187$) and 2.81% ($p = 0.023$).

From September to December, color changes in the cheeks include a 0.92% ($p < 0.05$) reduction in lightness and a 9.36% ($p < 0.001$) increase in redness. In the forehead, the skin redness increased by 4.59% ($p = 0.091$).

4 | DISCUSSION

From June to December, TEWL, a skin barrier-related indicator, changed greatly in the mask-skin zone compared to the non-mask-

wearing area. In particular, the TEWL of the cheeks and perioral area showed a significant difference compared to the forehead (non-mask-wearing area). Skin hydration of the mask-skin zone also decreased. The greatest change in skin hydration was in the perioral area likely due to its direct exposure to warm breath. Compared to the forehead, the mask-skin zones (cheeks, perioral area, and chin) were significantly different. Skin barrier function was weakened, and skin became dry at the same time. These changes would indicate deterioration in the skin condition. The mask-wearing areas are hot and humid, similar to the climate of a tropical rainforest. This implies that it is difficult to ventilate in these areas due to the occlusion effect of face masks.^{9,10} This mask-microclimate combined with rapid environmental changes caused by the repetition of wearing and taking off the mask was thought to have weakened the skin. In addition, the mask-skin zone exposed to warm body temperature breath showed a significant difference from the non-mask-wearing area.¹¹

From June to December, the amount of skin keratin also increased in the mask-skin zone. Skin keratin amount in the cheeks, perioral area, and chin significantly increased and showed a significant difference compared to the keratin amount in the forehead. The amount of keratin on the forehead also significantly increased, but the rate was lower than that in the mask-skin zone. The measurement period included both the summer and fall, which is a typical period when the skin begins to dry out.^{12,13} The change in skin keratin amount in the mask-skin zone was higher than that in the non-mask-wearing area. This was thought to be affected by the mask-microclimate due to the reduction in skin hydration, and this mask-microclimate might have led to significant differences between the mask-skin zone and non-mask-wearing area. Increased skin keratin amount might be a result of accumulating of dead skin cells or more easily exfoliating. This result also could be associated with changes in skin health,¹⁴ such as skin dryness or weakening of skin barrier.

The skin pore area was measured on the mask-skin zones (e.g., cheeks and perioral areas) and non-mask-wearing area (i.e., forehead). From June to December, the skin pore area of the mask-skin zone significantly increased. Although the skin pore area of the forehead also increased, the difference was not significant. Compared to the forehead, the skin pore area of the cheeks was significantly different.

Skin elasticity significantly decreased in both the mask-skin zones and the non-mask-wearing area. These may be due to endogenous aging or stress¹⁵ caused by the rapid intervals of wearing and taking off the mask. As a result, these may have affected the overall facial skin and the local skin surface. However, its exact etiology is not clear since there are no data from the same subjects describing the period when they did not wear masks. If the skin elasticity decreases, the skin pore area may look wider. However, in this study, the area most affected by skin elasticity and skin pore area was different. The reduction rate of skin elasticity was the highest on the forehead, while the rate of skin pore area increase was higher in the cheeks and perioral area. This increase in skin pore area in the mask-skin zone was thought to be affected by a decrease in skin elasticity and continuous exposure to high temperature and humidity.¹²

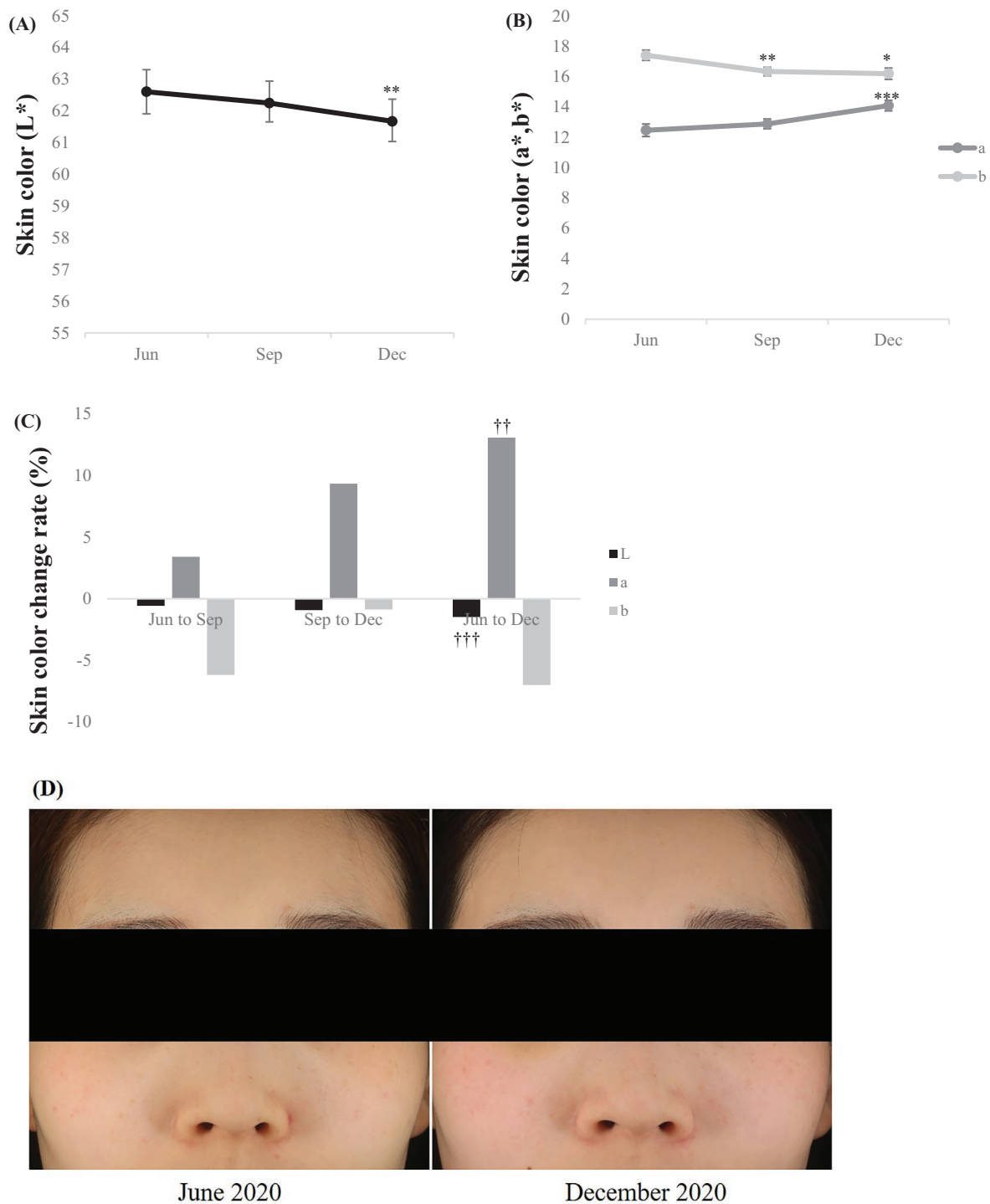


FIGURE 7 Skin color measurements in June, September, and December. (A) Skin lightness results of the cheeks. (B) Skin redness and yellowness result in the cheeks. (C) Skin color change rate of the cheeks from June to September, September to December, and June to December. (D) Image of the skin color variations during the 6-month period

The skin color was expected to decrease the lightness of the non-mask-wearing area because the mask-skin zone was covered with a mask, while the non-mask-wearing areas were exposed to ultraviolet light. However, our results were not consistent with this. From June to December, statistically significant skin color changes of the cheeks

include an increase in redness and a decrease in lightness and yellowness. There was no significant difference in the skin color of the forehead during this period. Compared to the forehead, the lightness and redness of the cheeks were significantly different. Despite the mask type and individual differences, masks are usually in direct contact with

TABLE 4 Skin change rate (%) from June to December

	TEWL	Skin hydration	Skin keratin amount	Skin pore area	Skin elasticity (R2)
Cheeks	48.31% ^{***,†††}	-8.70% [†]	53.29% ^{***,†††}	84.87% ^{**,††}	-7.36% [*]
Perioral area	16.67% ^{*,†}	-19.65% ^{*,†}	27.99% [†]	98.75% ^{***}	-6.43% ^{***}
Chin	11.51%	-10.90% ^{*,†}	23.50% [†]	-	-10.22% ^{***}

Abbreviation: TEWL, trans-epidermal water loss.

* $p < 0.05$.

** $p < 0.005$.

*** $p < 0.001$ September or December versus June.

† $p < 0.05$.

†† $p < 0.005$.

††† $p < 0.001$ mask-skin zone (mask-wearing area) versus non-mask-wearing area.

the cheeks that may cause physical irritation and redness.¹⁶ In addition, the skin microclimate¹⁷ caused by mask-wearing may also play a role. The lightness and yellowness of the skin may also be affected by mask-wearing; however, the exact mechanism is unclear.

Skin temperature and skin redness showed a significant change after wearing masks for a short period.⁵ However, these changes were relatively small in this long-term study. It is thought that these two measurements are highly related to the homeostasis of body temperature. Although temporary changes are possible, chronic changes in baseline may be difficult to achieve.

In this study, we analyzed skin changes during the 6-month period of wearing a mask continuously and daily. Skin changes caused by long-term wearing of masks were associated with skin barrier-related changes and dryness. In the mask-skin zone, TEWL (a skin barrier indicator) increased, but skin hydration decreased. These changes in TEWL and skin hydration were thought to be related to the increased skin keratin amount and skin pore area. Moreover, these may also influence the reduction in skin elasticity of the mask-skin zone as it weakened and dried from baseline (Table 4).

5 | CONCLUSION

Wearing masks daily is no longer limited to specific occupational environments due to the pandemic. In response to wearing masks, the human skin does not change easily because it tries to maintain homeostasis. However, there is a possibility that skin changes slowly in the long run. In this study, we evaluated the effects of long-term wearing of masks on facial skin. There were limitations in that we did not have skin measurement data without a mask at the same time in every subject. Moreover, seasonal changes may have also influenced the results. However, these seasonal changes vary in characteristics and aspects, while our results show that mask-skin zones had similar changes in each area, these changes were significantly different compared to non-mask-wearing areas. To confirm the clear etiology, further studies are needed in comparison to skin changes during periods without a mask. This paper highlights the changes in skin characteristics of the mask-skin zones caused by the long-term wearing of masks. It is, hence, crucial that special care should be focused on the mask-skin zones.

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