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An innovative concealing technology designed to enhance the beauty of every skin tone with a natural-look and high coverage

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1. Introduction.

People of all skin tones turn to products like foundations, primers, and concealers to address their skin concerns. These products are designed to enhance natural beauty while boosting confidence and radiating a positive energy [1]. Makeup products usually achieve coverage with titanium dioxide and iron oxide. Titanium dioxide is a white powder that conceals skin imperfections by reflecting and scattering light. Iron oxide is a colored powder that absorbs specific wavelengths of light, making it suitable for skin tones. By adjusting the ratio of titanium dioxide and iron oxide according to skin tone and light reflection, makeup products can be tailored to suit various skin tones. From previous studies, a wide range of skin tones can be categorized into six groups based on their spectral reflectance characteristics, as shown in Fig. 1 [2]. For lighter skin tones, which reflect more light, a higher ratio of titanium dioxide to iron oxide provides strong coverage through reflection. In contrast, for darker skin tones, a higher ratio of iron oxide to titanium dioxide improves light absorption but results in poor coverage due to iron oxide aggregation and limited light scattering. While additional layers can slightly improve coverage, they lead to a heavy, powdery finish. Also, increasing titanium dioxide enhances coverage but causes a white cast, making it challenging to achieve both adequate coverage and a natural finish for darker skin tones.

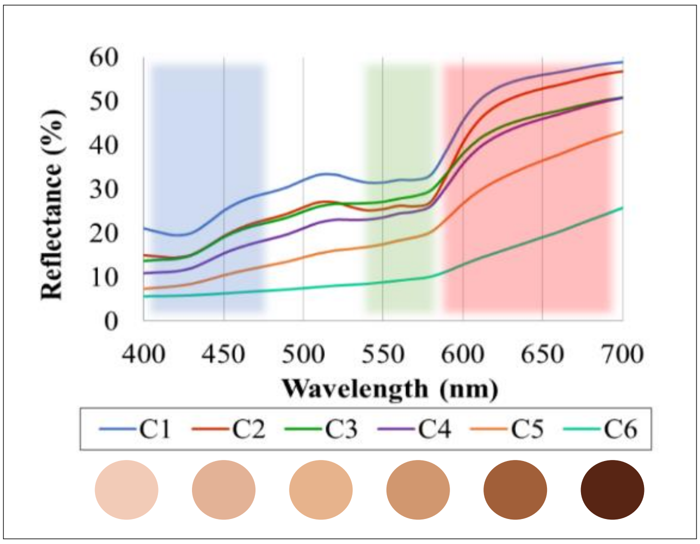

Figure 1. Average spectral reflectance for each skin tone category. Adapted from [2] Kakimoto, R (IFSCC 2022), and the representative skin tone swatches for C1-C6

To overcome this challenge, two main approaches are necessary: first, enhancing the dispersion of iron oxide to improve light absorption, thereby leading to high coverage, and second, utilizing the reflection and scattering properties of titanium dioxide while preventing an unnatural white cast. To achieve this, we propose a novel concealing technology called “Iron Oxide-mixed Large Titanium Dioxide” (hereafter, IOLTD) . This approach targets both the dispersion of iron oxide and the reduction of the mismatch between the spectral reflectance of titanium dioxide and the skin, providing sufficient coverage with only a small amount of product, while avoiding a white cast and ensuring a natural finish. Regarding the dispersion of iron oxide, we considered the collision energy involved in dispersion. When materials collide, the force of collision increases with the mass of the particles. By using large titanium dioxide particles, a strong energy is generated during collisions, helping to break up the aggregation of iron oxide and improve its dispersion. For a natural finish, we considered the spectral reflectance of titanium dioxide with different particle sizes. It is known that light scattering is maximized when the particle size of the scattering agent is approximately half the wavelength of the scattered light. For this reason, titanium dioxide with a particle size of 200–300 nm is used in makeup products to scatter light most efficiently in the visible range of 400–700 nm [3]. Darker skin tones mainly reflect melanin properties, with low reflectance in the blue and green wavelengths (400–570 nm). Using titanium dioxide with a larger particle size (400–1000 nm) helps reduce blue and green light reflection. Moreover, several studies have shown that enhancing red light reflection (above 560 nm) can improve the natural appearance of skin tone [4][5]. As the particle size increases, the reflection and scattering of titanium dioxide decrease; we consider this to be more suitable for darker skin tones. Although the reduction in diffuse reflection from titanium dioxide lowers its contribution to coverage, this shortfall can be compensated by the use of highly dispersed iron oxide. By dispersing iron oxide with large titanium dioxide particles, we aim to achieve both high coverage and a natural finish for darker skin tones.

Herein, we report on the composite conditions of titanium dioxide and iron oxide for IOLTD, the functionality of IOLTD, and the coverage and naturalness of a consumer product that utilizes IOLTD. We focus the application on high-coverage concealers for darker skin tones, where high powder content presents greater formulation challenges.

2. Materials and Methods.

2.1. Manufacturing of IOLTD

IOLTD-1, -2, and -3 were prepared by mixing titanium dioxide particles (1000, 700, and 400 nm) with black, red, and yellow iron oxides using a tabletop mixer (Wonder Crusher, Osaka Chemical Co., Ltd.) at a peripheral speed of 40 m/s for 10 minutes. The mixing ratios were adjusted to approximate the L*a*b* values in CIELAB space and spectral reflectance reported for darker skin tones in previous studies [1]. L*a*b* values and spectral reflectance were measured using a spectrophotometer CM-700d (KONICA MINOLTA, INC.) after pressing each IOLTD onto a metal plate.

2.2. Properties of IOLTD

2.2.1. Structural analysis of IOLTD

The microstructure of IOLTD 1–3 was observed using Scanning Electron Microscopy (SEM Hitachi High-Tech Co.), and the iron oxide and titanium dioxide were detected by Energy-Dispersive X-ray Spectroscopy (EDS) mapping.

2.2.2. Dispersion of iron oxide based on the size of titanium dioxide

To evaluate the effect of titanium dioxide particle size on the dispersion of iron oxide, composites were prepared using 80% black iron oxide and 20% titanium dioxide (1000, 700, and 400 nm) following the method described in Section 2.1. The composites were then dispersed in cyclopentasiloxane at 0.1 wt% using a disperser at 3000 rpm for 10 minutes. After allowing the mixture to stand for 60 minutes, the particle size (μm) was calculated using Stokes' law, assuming densities of 4.2 and 5.0 g/cm^3 for titanium dioxide and iron oxide, respectively.

2.3. Functionalities of concealer containing IOLTD

2.3.1. Coverage of concealer containing IOLTD

The hiding power was calculated in accordance with ISO 6504-3 to evaluate the coverage of IOLTD in makeup formulations. Wax and oil-based concealers A–E were prepared using a roll mill. All concealers contained equal amounts of titanium dioxide and iron oxide. Concealers A, B, and C contained 22.5 wt% of IOLTD-1, -2, and -3, respectively. Concealer D included black, red, and yellow iron oxides and 1000 nm titanium dioxide, meaning that it contains the same particle size and composition ratio of titanium dioxide and iron oxides as IOLTD-1, but it was not processed to form IOLTD. Concealer E contained the same iron oxides and 250 nm titanium dioxide, which is widely incorporated into typical concealers. Each concealer was applied to a black and white chart at 0.4 mg/cm². L*a*b* values of the black and white areas were measured as described in Section 2.1, and hiding power was calculated as the ratio of the L* value on the black area to that on the white area (i.e., L*_black / L*_white).

2.3.2. Spectral reflectance of concealer containing IOLTD

Concealers A, D, and E were placed between two glass plates with sufficient thickness to prevent translucency, and their spectral reflectance was measured according to the method described in Section 2.1.

2.4. Evaluation of skin tone improvement with IOLTD concealer.

To evaluate the enhancement of uneven skin tones and the natural finish of the concealers, Concealers A and D were applied at the same thickness as in Section 2.3.1 to both blemished and non-blemished skin areas of participants exhibiting uneven skin tones. L*a*b* values were measured according to the method described in Section 2.1. The color difference (ΔE) between blemished and non-blemished skin areas was calculated before and after the application of concealers to evaluate the covering effect of the concealers. This study was approved by an independent ethical review board and conducted in accordance with the principles of the Declaration of Helsinki.

3. Result

3.1. Manufacturing of IOLTD

IOLTD-1, -2, and -3 were prepared using the pigment compositions shown in Table 1. All iron oxides and titanium dioxide used complied with international cosmetic colorant regulations, and the synthesized IOLTDs also fulfilled these requirements. The color appearance of each IOLTD is presented in Fig. 2 (top), and their L*a*b* values are listed in Table 1. Among them, IOLTD-1, prepared with 1000 nm titanium dioxide, exhibited the lowest lightness (L* value) and highest chroma. The spectral reflectance of IOLTD-1 and -2 closely aligned with darker skin tones, indicating that IOLTD-1 and -2 were well-suited for the darker skin tones (Fig. 2, bottom).

Table 1. Ratio of iron oxide and titanium dioxide and L*a*b* value

	IOLTD-1	IOLTD-2	IOLTD-3	Darker skin tone
Titanium dioxide	20% (1000 nm)	20% (700 nm)	20% (400 nm)	-
Black iron oxide	39%	39%	39%	-
Red iron oxide	33%	33%	33%	-
Yellow iron oxide	8%	8%	8%	-
L*	38.09	38.66	43.30	37.65
a*	13.87	13.24	11.40	10.59
b*	15.28	14.45	12.30	12.43

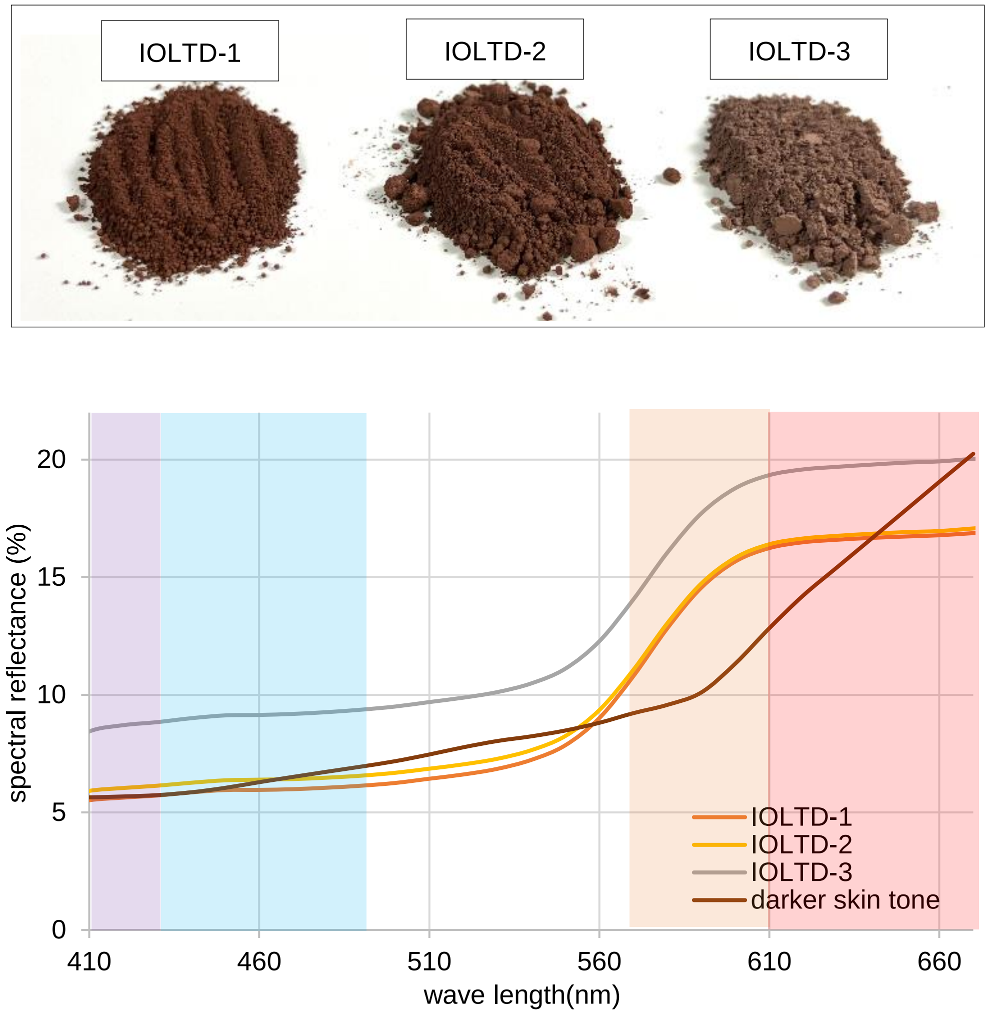

Figure 2. Images of IOLTD-1, -2, and -3 (top), and their spectral reflectance (bottom).

3.2. Properties of IOLTD

<u>3. 2.1 Structural analysis of IOLTD</u>

To observe the distribution of titanium dioxide and iron oxides in IOLTD-1, 2, and 3, SEM and EDS analyses were conducted. In the EDS images, blue signals indicate iron oxide, and purple signals indicate titanium dioxide. As shown in Fig. 3, aggregated titanium dioxide particles were observed in IOLTD-2 and IOLTD-3, whereas in IOLTD-1, titanium dioxide particles tended to appeared individually dispersed without aggregation. The needle-like particles are red and yellow iron oxides, and spherical particles are black iron oxide. Focusing on black iron oxide, as indicated by the red triangles in Fig. 3, relatively large aggregates of black iron oxide were observed in IOLTD-2 and IOLTD-3, whereas in IOLTD-1, the degree of aggregation of black iron oxide appeared to be improved.

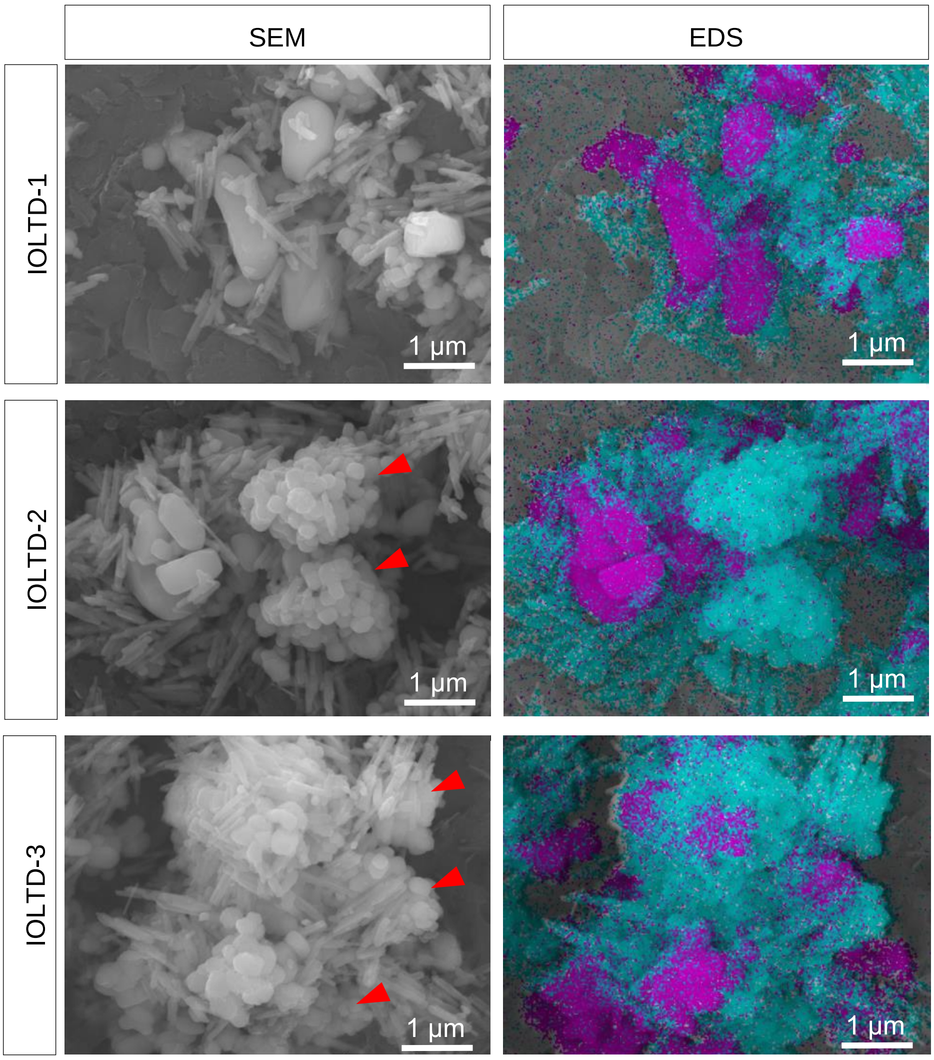

Figure 3. SEM images (left) and EDS mapping (right) of IOLTD-1, -2, and -3. In the EDS images, blue signals indicate iron oxide, and purple signals indicate titanium dioxide.

3.2.2 Dispersion of iron oxide based on the size of titanium dioxide

In order to evaluate the dispersion of iron oxide depending on the particle size of titanium dioxide, the average particle size in the dispersion was calculated from Stokes' law. As the particle size of titanium dioxide increased from 400 nm to 700 nm to 1000 nm, the average particle size of iron oxide decreased. These results suggest that increasing the particle size of titanium dioxide improves the dispersion of iron oxide.

Table 2. Average particle size calculated based on Stokes' law

	Particle Size Distribution
Iron oxide with 400 nm titanium dioxide	2.7 μm
Iron oxide with 700 nm titanium dioxide	2.3 μm
Iron oxide with 1000 nm titanium dioxide	2.1 μm
Only iron oxide	2.4 μm

3.3. Functionalities of concealer containing IOLTD

3.3.1. Coverage of concealer containing IOLTD

The composition and L*a*b* values of Concealers A–E are shown in Table 3. Images of each concealer on a black and white chart and their hiding power (L*_Black / L*_White) are shown in Fig.4. Among Concealers A–C, Concealer A exhibited the highest hiding power, indicating that the particle size of titanium dioxide in IOLTD affects hiding power. Although Concealers A and D contain the same titanium dioxide, Concealer A exhibited higher hiding power, indicating that it is crucial to mix titanium dioxide with iron oxide to form IOLTD. Concealer E, which contains 250 nm titanium dioxide, showed the second highest hiding power after Concealer A. However, its unnatural whiteness on the black chart suggests that it does not blend well with darker skin tones. Considering these results overall, Concealer A was the most effective in achieving both high hiding power and a dark tone simultaneously.

Table 3. Pigment compositions and corresponding L*a*b* color values of concealers A–E

	Concealer A	Concealer B	Concealer C	Concealer D	Concealer E
IOLTD	IOLTD-1	IOLTD-2	IOLTD-3	-	-
titanium dioxide	-	-	-	1000 nm	250 nm
iron oxide	-	-	-	black, red, yellow	black, red, yellow
L*	35.75	35.93	37.15	35.30	36.16
a*	6.32	5.97	6.45	5.49	6.16
b*	7.16	6.74	7.58	5.93	6.24

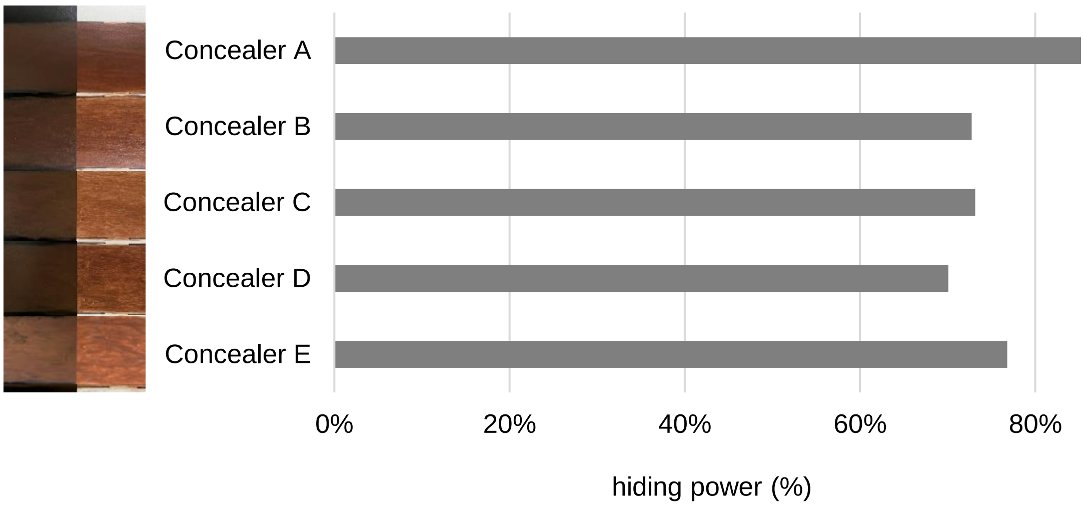

Figure 4. Hiding power of concealers A–E. Images on the left show the appearance of a black and white chart after application of each concealer.

3.3.2. Spectral reflectance of concealer containing IOLTD

The spectral reflectance of Concealers A, D, and E is shown in Fig. 5. Compared with Concealer D, which was formulated with iron oxides and 1000 nm titanium dioxide, Concealer A containing IOLTD-1 exhibited higher reflectance in the orange to red region (above 560 nm).

In contrast, when compared to Concealer E, which was formulated with 250 nm titanium dioxide, Concealer A showed lower reflectance in the purple to blue region (below 500 nm).

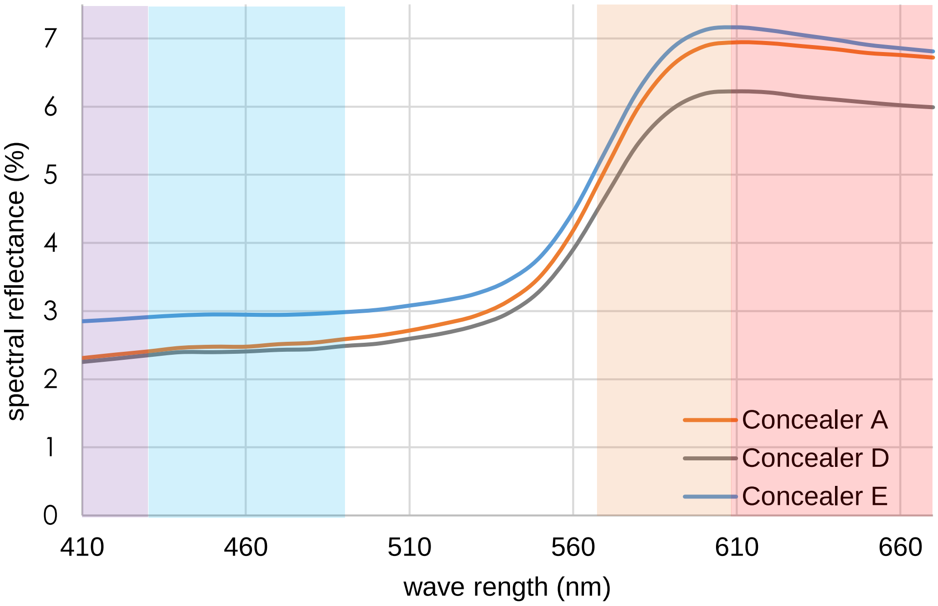

Figure 5. Spectral reflectance data of concealers A, D, and E.

3.4. Evaluation of skin improvement with concealer containing IOLTD

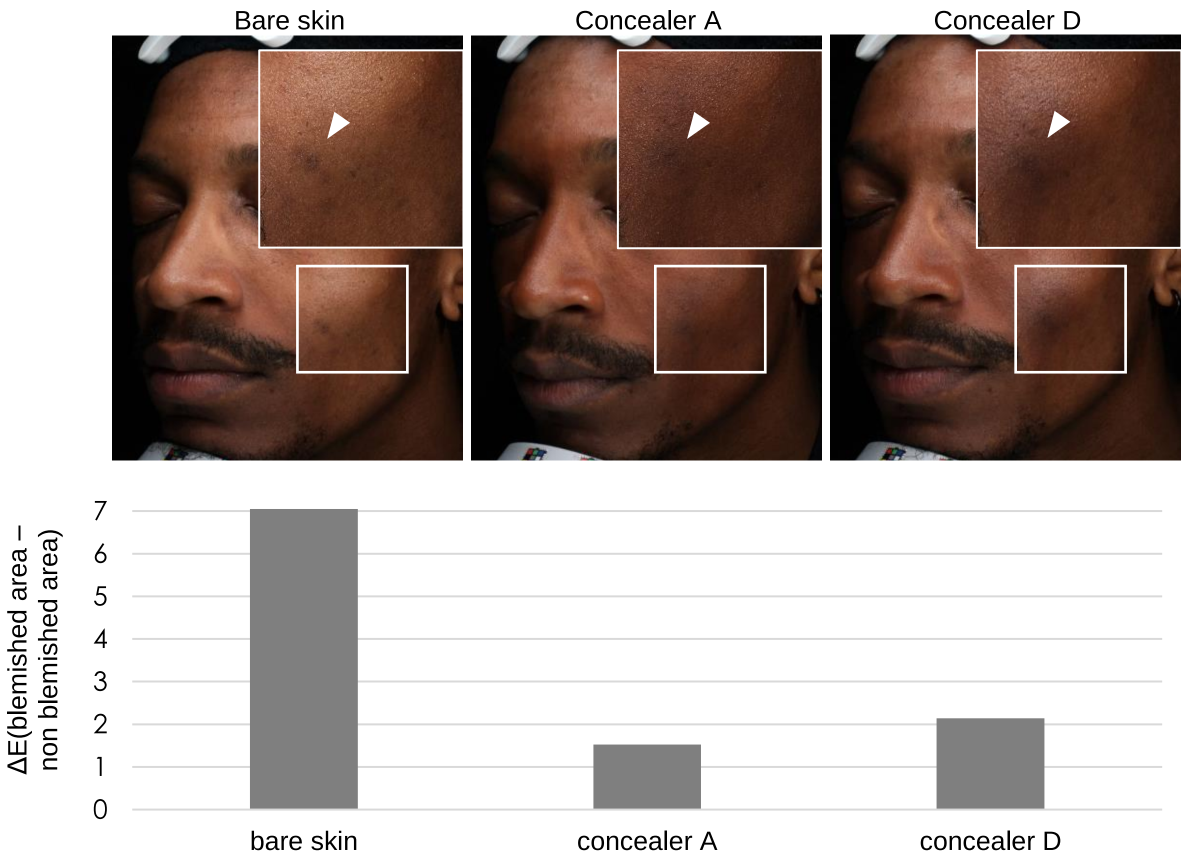

Figure 6. Images of bare skin and skin after application of Concealers A and D (top). Color difference (ΔE) between blemished and non-blemished areas for bare skin and after application of Concealers A and D (bottom).

Seven participants with darker skin tones and sufficiently large blemished areas for measurement were selected, and Concealers A and D were applied to their skin. When no product was applied, the average ΔE between blemished and non-blemished areas was 7.05. In contrast, when Concealer A was applied, the average ΔE decreased to 1.53, and it was visually confirmed that blemishes were naturally covered. When Concealer D was applied, the average ΔE decreased to 2.14, but blemishes remained noticeable.

4. Discussion.

4.1. Dispersion of iron oxide and the coverage of concealer containing IOLTD

The dispersion of iron oxide was most improved by combining it with 1000 nm titanium dioxide. IOLTD is produced by strongly dispersing titanium dioxide and iron oxide in a dry dispersing process. It is hypothesized that during this process, titanium dioxide acts as a kind of grinding bead, helping improve the dispersion of iron oxide. In order to break the aggregation of iron oxide, a certain amount of energy from the collision of the titanium dioxide particle may be required. As the size of the titanium dioxide particles increases from 400 nm, 700 nm and 1000 nm, the energy in a single collision increases accordingly. It can be inferred that at 1000 nm, the energy was sufficiently high to effectively disrupt the aggregation of iron oxide. The higher hardness of titanium dioxide compared to iron oxides may also have contributed to the successful dispersion. Despite having the same ratio and particle size of titanium dioxide and iron oxides, Concealer A using IOLTD led to superior concealing performance compared to Concealer D, suggesting that improving dispersion of iron oxide is crucial for achieving significant coverage in darker skin tones.

4.2. Spectral reflectance of concealer containing IOLTD and natural finish

Concealer A showed a low reflectance in the short wavelength range and a high reflectance in the long wavelength range, which aligned with the spectral reflectance trends identified in previous studies as being most effective for a natural and beautiful skin appearance. The low reflectance in the short wavelength range is likely due to the influence of titanium dioxide particle size. The high reflectance in the long wavelength range can be attributed to both the reflective properties of large titanium dioxide particles and the improved dispersion of iron oxide. This characteristic is desirable not only for darker skin tones but also for lighter skin tones, suggesting that IOLTD has the potential for broad application across various skin tones. To evaluate the applicability of IOLTD to lighter skin tones, we additionally formulated a version tailored for such skin tones and confirmed its suitability for manufacturability. Further investigation into formulations for lighter skin tones is planned.

5. Conclusion

In this study, we focused on addressing the significant challenge of achieving both high coverage and a natural finish for darker skin tones within concealing technologies. The key to IOLTD lies in the use of large titanium dioxide particles. Large titanium dioxide particles have the characteristic of reducing the unnatural white cast due to their lower reflectance of short wavelength light range. In addition to its inherent optical properties, this study reveals that large titanium dioxide contributes to achieving both higher coverage and a more natural finish by improving the dispersion of iron oxide. Within the IOLTD, the large titanium dioxide particles improve the dispersion of iron oxides by reducing their aggregation through collision energy, thereby enhancing coverage in darker skin tones. While large titanium dioxide particles are generally known to offer lower hiding power than smaller particles (200–300 nm), our results demonstrate that, when used in formulations for darker skin tones, they can provide superior coverage. This represents a novel and groundbreaking innovation in cosmetics for darker skin tones. It is also noteworthy that IOLTD is composed of materials with excellent usability, and complies with international cosmetic colorant regulations. We believe that IOLTD has the potential not only for darker skin tones but also for lighter skin tones, regardless of race, gender, or age. IOLTD, which combines high coverage with naturalness, is suitable for both localized imperfections and widespread skin concerns, expanding the scope of concealing applications. Its application extends beyond concealers to other categories such as foundations with reduced powderiness, sunscreens by minimizing a white cast effect even on darker skin tones, and appearance care products. As such, IOLTD is expected to have a broad impact on the cosmetics industry.

6. References

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