Development of a base makeup with a pearl luster using three-dimensional computer graphics

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Short summary

Pearls have long attracted attention for their elegant beauty. In this study, we attempt to formulate a base makeup that gives a pearl-like luster to human face. Applying an optical property of pearls called "blurring" to face images reproduced in three-dimensional computer graphics (3DCG) increased the visual appeal. Therefore, in this study, we formulated a base makeup that imparts blurring to a real human face. Initially, the reflective characteristics of blurring were calculated simulating the reflection and transmission of light in a multilayer structure of thin films. As such, we developed a powder ingredient having a similar bidirectional reflectance distribution function (BRDF), which defines how light is reflected from object surfaces with a layered structure. The powder ingredient was a plate-like powder composed of synthetic mica with titanium dioxide and aluminum hydroxide. Although it had high reflectance, it did not produce an unnatural finish to the face. We subsequently formulated a base makeup that contained the powder described above. Then extracted BRDF and surface reflection light components from a 3DCG face image as reflection characteristics and compared these characteristics with those of a Bio Skin Doll (Beaulax, Japan) with the makeup. Applying a prototype base makeup to the Bio Skin Doll increased the light reflectance of whole face and produced reflectance properties similar to the human face image on which blurring was applied.

1. Introduction

The attractive quality of pearls lies in their smooth luster and deep gloss due to complex optical phenomena related to their multilayer structure. In this study, we attempt to apply the luster of pearls to a base makeup. Until now, we performed visual evaluations using facial 3DCG taking into account optical phenomena observed in pearls and a multiple regression analysis of the degree of optical "blurring" and "interference light" components. Data revealed that "blurring" was the most influential factor, with the most attractive image generated when it alone was used. The pearly skin

image in Figure 1 shows the most attractive image. [1][2][3][4].

Figure 1. Facial 3DCG image of pearly skin.

Many studies have examined the application of the luster of pearls to cosmetics. For example high-brightness powder ingredients, such as pearly powder, consist of synthetic mica and titanium dioxide [5]. In many cases, cosmetics that intend to impart luster of pearls are predominantly composed of powder with high reflectance or any ingredients derived from pearls, like shell powder.

Therefore, in this study, we focus attention on optical characteristic of the pearls and attempt to identify, by using the 3DCG technology, reflective characteristics of the human face on which luster of pearls is applied and to formulate a base makeup that impart similar reflective characteristics to real human face. The initial step was to develop a powder ingredient embodying the reflective characteristics of blurring. The subsequent step was to formulate a base makeup which, when applied to a Bio Skin Doll, embodied similar reflective characteristic to the pearly skin image. The reflective characteristics of the pearly skin image at the microscopic level were evaluated using the BRDF. In addition, the specular reflection of this image at a macroscopic level was determined through multiperspective light imaging.

2. Development of the pearly blurring powder (PB powder)

2.1. Structure of the powder ingredient

The BRDF of blurring calculated by physical simulation using the Monte Carlo method shows the lowest reflectance at a 45° incident angle while distorting to the right with an increasing incident angle (Figure 2). The figure demonstrates higher reflectance affected by the Fresnel reflection.

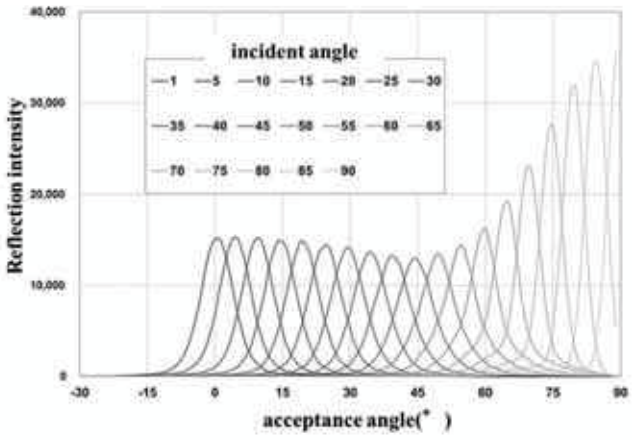


Figure 2. BRDF of blurring.

We developed a powder ingredient having similar BRDF to the blurring of pearls. Generally, powder ingredients show different reflective characteristics depending on particle composition and shape. Particularly for plate-like particles, reflectance is known to increase with particle size.

Since the BRDF of blurring exhibited a strong specular reflection, we designed a powder having high reflectance. However, when a large particle powder ingredient with high reflectance was used in the base makeup composition, the size and reflectance intensity caused unnatural finish. Therefore, for the ingredient embodying the BRDF of pearls blurring, we designed a powder which based on synthetic mica with a particle size of about 20 μm. To increase the reflection intensity, it was coated with titanium dioxide and aluminum hydroxide. We subsequently named this powder as Pearly Blurring powder (PB powder).

2.2. Evaluation methods

The BRDF of blurring was calculated taking into account all the reflections and transmissions in a multilayer structure, as shown in Figure 3. This structure simulates the multilayers of a pearl.

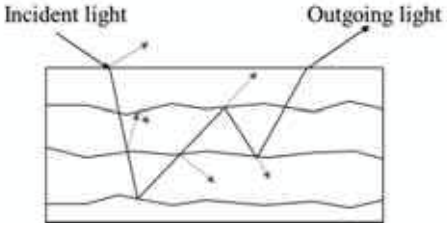


Figure 3. Multilayer structure simulated for calculation of BRDF.

Therefore, the evaluation of powders in a multilayer structure should be performed. For this reason, a multilayer powder structure was created on a coating paper using a 50% octyl dodecanol ethanol solution as the binder. In order to make the multilayer powder structure, the powder was overlayered and flattened by a roller. This process was repeated until the surface of coating paper was covered completely, as shown in Figure 4. The BRDF of this sample was obtained by taking measurements with an optical gyro measuring machine (OGM) [6]. The powder was evaluated by comparing its BRDF with the BRDF of blurring. Comparison of the BRDFs was conducted at incident angles of 0°, 22°, 45°, and 67°. In addition to the PB powder, we evaluate mica,

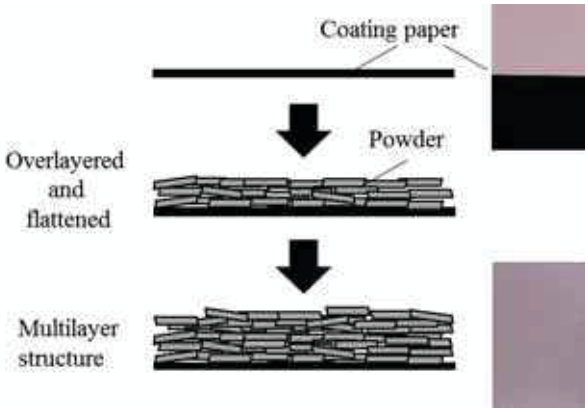


Figure 4. Forming a multilayer structure of the powder ingredient.

synthetic mica, and large particle powder, the so called pearly powder. Table 1 shows features of the powders.

Table 1. Features of powders evaluated.

Powder	Mica	Synthetic mica	Pearly powder	PB powder
Composition	Mica	Synthetic mica	Synthetic mica Titanium dioxide	Synthetic mica Titanium dioxide Aluminum hydroxide
Average particle size (μm)	45	20	100	21
The multilayer sample of powder				

2.3. Results and discussion

The BRDF of blurring, shown in Figure 5(a), was compared with the BRDFs of the powder (Figure 5), mica (Figure 5(b)), synthetic mica (Figure 5(c)), pearly powder (Figure 5(d)), and PB powder (Figure 5(e)).

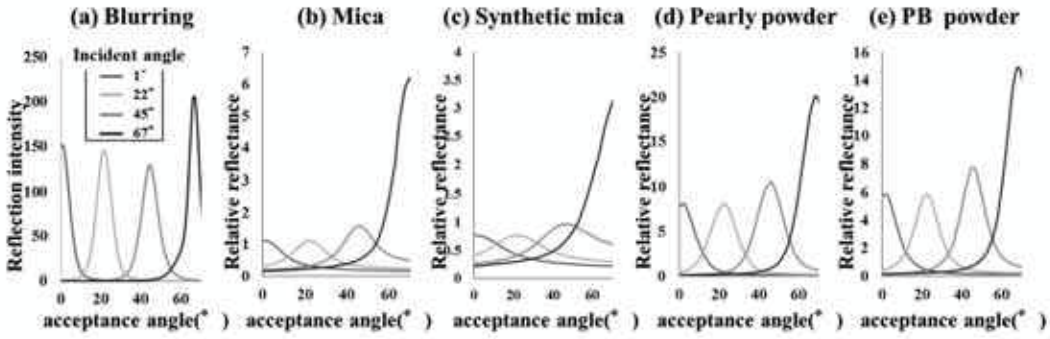
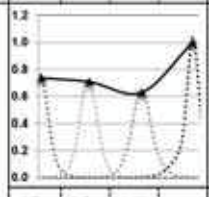
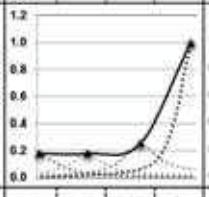
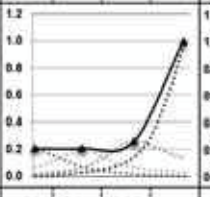
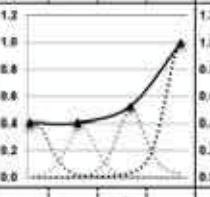
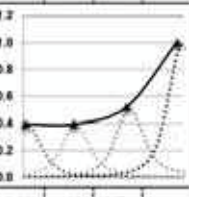


Figure 5. BRDFs of powders.

In order to evaluate the similarity of pearl blurring and powder BRDFs, we calculated the peak value locus showing the relative value of the reflection peak at each incident angle, with the reflection peak at 67° set as 1. We subsequently calculated the full width at half maximum (FWHM). In the graph, the peak sharpens as the FWHM decreases.

In addition, we calculated residual sum of squares (RSS) between the BRDF of blurring and the BRDF of powders that were fitted to the BRDF of blurring for the entire range of incident angles. The results are shown in Table 2.

Table 2 Analysis of BRDFs

Powder	Blurring				Mica				Synthetic mica				Pearly powder				PB powder			
Incident angle	1°	22°	45°	67°	1°	22°	45°	67°	1°	22°	45°	67°	1°	22°	45°	67°	1°	22°	45°	67°
Peak value locus																				
	0.74	0.71	0.63	1	0.18	0.18	0.25	1	0.21	0.21	0.26	1	0.41	0.41	0.53	1	0.39	0.39	0.52	1
FWHM	8	8	10	6	23	23	22	17	47	50	55	24	17	16	16	17	15	15	14	16
RSS	0				8.40				9.75				4.34				4.30			

Comparing BRDF of blurring with BRDF of powders at the peak value locus, mica and synthetic mica showed lower reflectance at 0°, 22°, and 45° compared to at 67°. On the other hand, pearly powder and PB powder exhibited higher reflectance at 0°, 22°, and 45°. In addition, comparing the FWHM, mica and synthetic mica had higher values due to a broad peak form. On the other hand, the pearly and PB powders show lower values because of their sharp peak form. Additionally, in the comparison of RSS, pearly and PB powders had lower values than mica and synthetic mica, indicating that the BRDF of pearly powder and PB powder are closer to the BRDF of blurring.

The above results suggest that mica and synthetic mica are not suitable ingredients to impart blurring. Moreover, despite pearly powder showing a close BRDF to that of blurring, it is not practical since the particle size is too large to be contained in cosmetics. PB powder on the other hand, exhibited a closer BRDF value to that of blurring in all analyses, and therefore more appropriately embodies the reflective characteristic of blurring than other powders.

2.4. Sensory evaluation

2.4.1. Evaluation of luster and attractiveness of the PB powder

We conducted sensory evaluation of powders formed in multilayer structures in two ways. The first was whether the powder exhibited “luster of pearls” and the second was whether the powder was “attractive”. Each powder was evaluated by 44 women, from 21 to 49 years old (32.2 ± 7.53, mean ± SD). First, the evaluators selected the powders by a multiple-choice test, with ratings out of 5, then they selected one powder in a single-answer test.

2.4.2. Result and discussion

Evaluation of the "luster of pearls" (Figure 6(a)) shows that the rating value of PB powder was 2.9, which is highest among all powders. Furthermore, Figure 6(b) shows that PB powder was selected by 61% of the respondents in the multiple-choice response, and in the subsequent single-answer question, as shown in Figure 6(c), PB powder was selected by 48% respondents.

For the evaluation of "attractiveness," PB powder also showed a high rating value of 3.7 (Figure 7(a)) significantly and 55% respondents selecting it in the multiple-choice response (Figure 7(b)). Moreover, as shown in Figure 7(c), in the single-answer test, the selective rate of PB powder was 45%.

From the above results, it was shown visually that the PB powder has the luster of pearls than other powders and that the luster of PB powder is considered attractive.

Figure 6. Rating value of "luster of pearls".
***P < 0.05, **P < 0.01 by Steel's test.**

Figure 7. Rating value of "attractiveness".
***P < 0.05, **P < 0.01 by Dunnett's test.**

3. Development of the base makeup embodying the pearly skin

3.1. Formulation of the base makeup

We formulated a liquid-type foundation containing 20% PB powder as base makeup, which embodied similar reflective characteristics to the pearly skin image when applied

to the Bio Skin Doll. The base makeup containing the PB powder was then evaluated in two distinct ways, using mica as a control. The first was by a comparison of BRDFs, and the second was by a comparison of the specular reflection component.

3.2. Evaluation of the base makeup by BRDF comparison

3.2.1. Evaluation methods

The BRDF of the pearly skin image was calculated using rendered images. Figure 8 shows the schematic of BRDF measurement. These images were obtained by setting the light and camera at an arbitrary angle with respect to the plane in which the optical characteristics of the pearly skin image were applied in the CG space. The image luminance value was considered as the reflection intensity at the optical acceptance angle of the incident light source.

The base makeup was applied to the Bio Skin Plate for evaluation and its BRDF was measured using OGM. The embodied blurring was evaluated at the microscopic level by comparing Bio Skin Plate and pearly skin images.

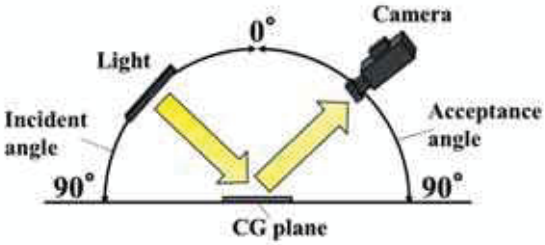


Figure 8. Schematic of BRDF measurements in the CG.

3.2.2. Results and discussion

Since the "blurring" component was added to the entire face image, the pearly skin image BRDF (Figure 9(a)) exhibited a high value for the entire acceptance angle, regardless of the incident angle. It was also found that the specular reflection component of each incident angle was slightly added at regular reflection angle in acceptance angle.

On the other hand, the BRDF of Bio Skin Doll with base makeup containing mica (Figure 9(c)) did not have much increased reflection intensity at any incident angle, as compared with the BRDF of Bio Skin Doll without anything applied, as shown in Figure 9(b).

However, for the Bio Skin Doll with base makeup containing PB powder (Figure 9(d)), the BRDF was close to that of the pearly skin image since the reflectance intensity increased for the entire acceptance angle range and the specular reflection component was added.

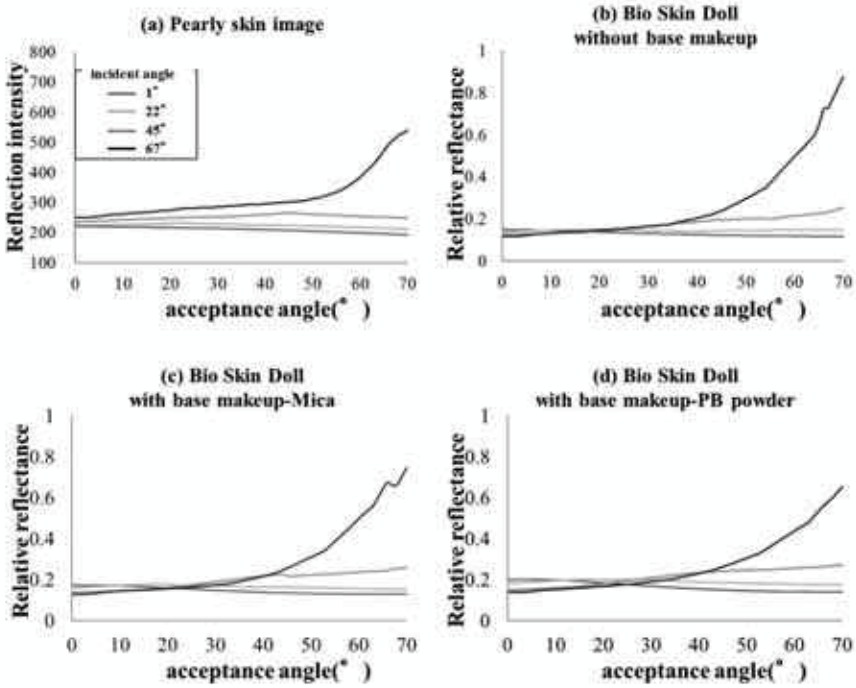


Figure 9. BRDFs of Bio Skin Doll.

We calculated the RSS between BRDFs of the pearly skin image and Bio Skin Doll, fitted to the BRDF of the pearly skin image at the entire incident angle range.

The RSS of the BRDF for Bio Skin Doll with base makeup containing mica was 9.35, whereas the RSS of the BRDF for Bio Skin Doll with base makeup containing PB powder was 4.83. It is therefore evident that the BRDF for the Bio Skin Doll with base makeup containing PB powder was closer to the BRDF for pearly skin image than the BRDF for the Bio Skin Doll with the base makeup containing mica.

3.3. Evaluation of the base makeup by comparison of the specular reflectance component

3.3.1. Evaluation methods

Blurring results from the light spreading caused by repeated regular reflection and specular transmission in the multilayer pearl structure. Therefore, blurring was configured as a specular reflection component in the pearly skin image. Its characteristics were elucidated by extracting the specular reflection images of the pearly skin and Bio Skin Doll, and visualizing these reflections through multiperspective imaging. The specular reflection image of the pearly skin image was obtained from the rendered image in the absence of diffused light and subsurface-scattering components.

On the other hand, the specular reflection image of the Bio Skin Doll was extracted by processing the image using polarized light (PL), as shown in Figure 10 [7].

The embodied blurring was evaluated at the macroscopic level by comparing specular reflection image of the pearly skin image and Bio Skin Doll at multiple perspectives in which incident and acceptance angles are paired with 0°, 22°, 45°, and 67°.

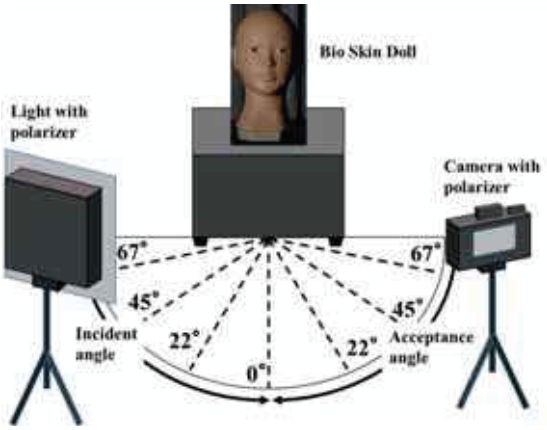


Figure 10. Extraction of the specular reflection. component from Bio Skin Doll .

3.3.2. Results and discussion

Figure 11 shows the specular reflection images from multiple perspectives, which were converted to heat map displays based on the luminance value. Figures 11(a) to 11(d) show specular images of pearly skin, Bio Skin with nothing applied, Bio Skin with mica applied, and Bio Skin with PB powder applied, respectively. We evaluated the changes in face luminance, and the average for the luminance for the entire face image was calculated (Figure 12).

For almost all combinations of incident angles and acceptance angles, the reflectance intensity of the pearly skin image was higher than that of the Bio Skin Doll with nothing applied. On the other hand, the specular reflection component of Bio Skin Doll with base makeup containing mica slightly increased for all combinations of incident angles and acceptance angles relative to Bio Skin Doll with nothing applied.

However, using the specular reflection component of Bio Skin Doll with the base makeup containing PB powder, the luminance of entire face for all combinations of incident angles and acceptance angles increased more than that of mica. The luminance of entire face with the base makeup containing PB powder particularly increased at lower incident angles, as shown in Figure 12.

For the above reasons, the application of the base makeup containing PB powder to Bio Skin doll most closely represented the pearly skin face image.

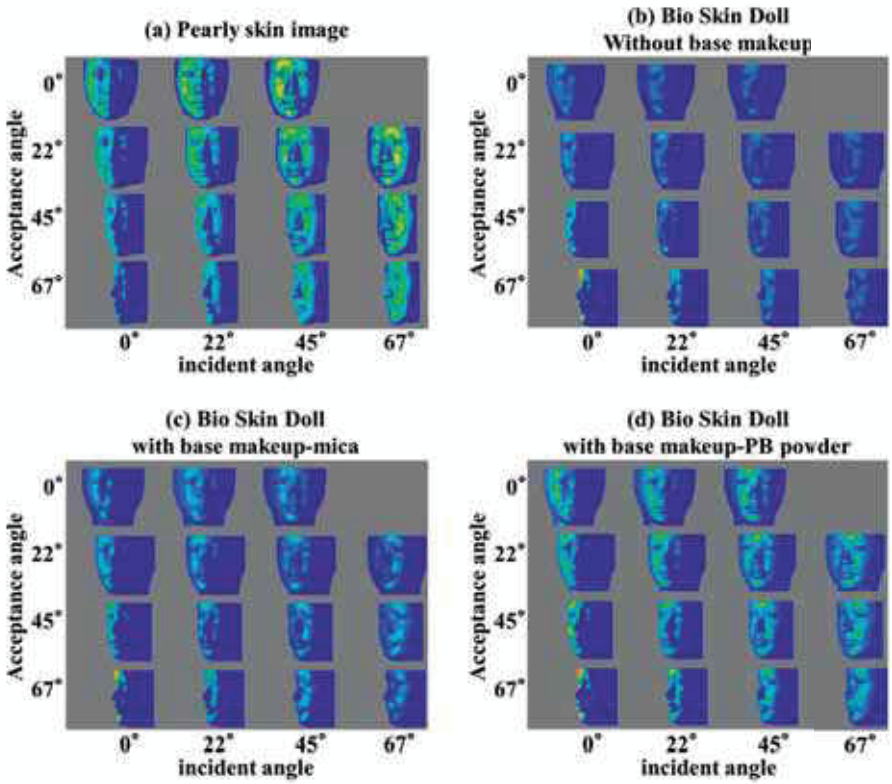


Figure 11 Distribution of the specular reflection component on face images.

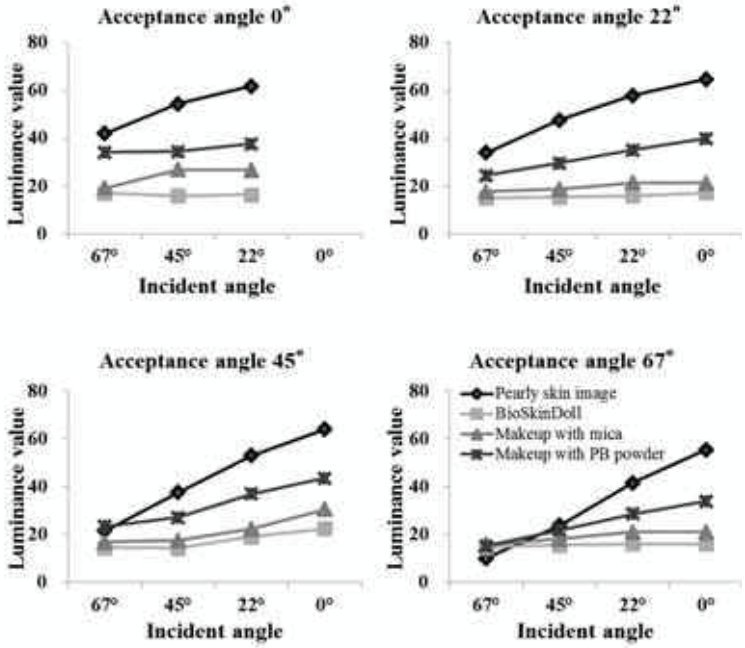


Figure 12 Average luminance of face images at each incident angle.

3.4. Sensory evaluation of base makeup

3.4.1. Evaluation of the Bio Skin Doll

Forty-four Japanese women, from 21 to 49 years old (32.2 ± 7.53, mean ± SD) conducted the sensory evaluations. They visually evaluated the Bio Skin Doll to which we applied base makeup containing mica or PB powder. First, they gave a rating out of 5 on the basis of how closely the Bio Skin Doll resembled the pearly skin image and selected which bears more resemblance. Then, they gave a rating out of 5 on the attractiveness of the Bio Skin Doll and selected which is more attractive.

3.4.2. Results and discussion

Figure 13 (a) indicated that the rating value of the Bio Skin Doll with base makeup containing PB powder was 3.3, which is significantly higher than that of mica. Moreover, the selective rate is higher (Figure 13(b)). Furthermore, the rating value for attractiveness was 3.3, which is higher than that of mica (Figure 14(a)). In addition, the selective rate is higher (Figure 14(b)).

These results indicated that base makeup containing PB powder is considered to be able to impart more luster of blurring to the Bio Skin Doll than traditional base makeup.

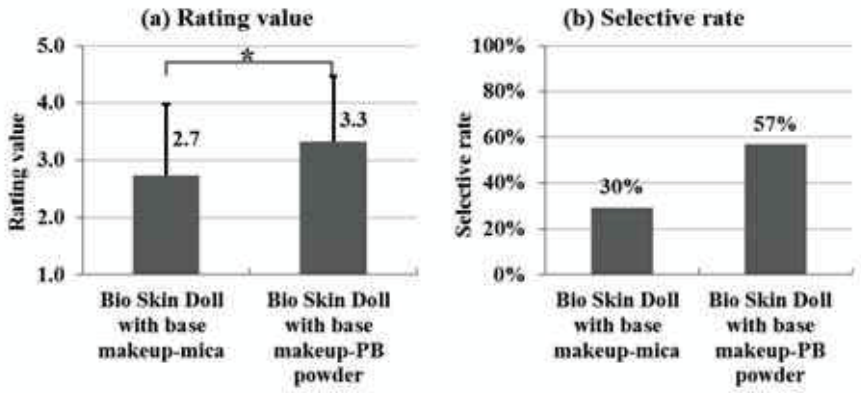


Figure 13. Resemblance evaluation to the pearly skin image. *p<0.05, **p<0.01 by Student's t test.

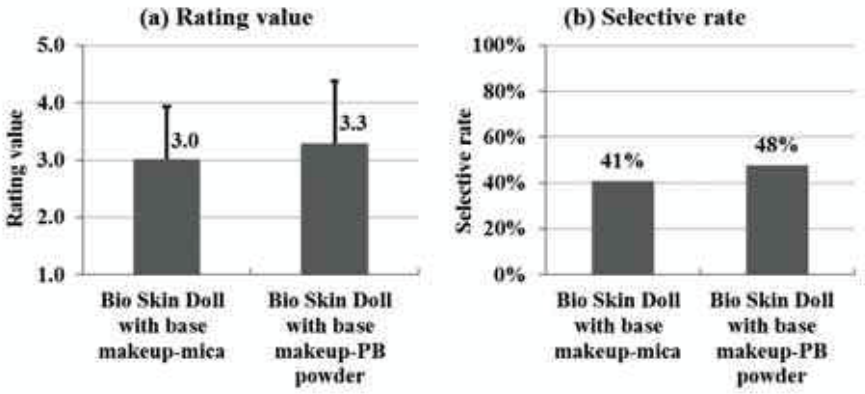


Figure 14. Rating value of attractiveness.
***p<0.05, **p<0.01 by Student's t test.**

4. Conclusion

In this study, we focused on the blurring that enhances the attractiveness of human face images by applying the optical property of pearls, and we subsequently developed a base makeup embodying the luster of blurring for the human face.

For the ingredient embodying blurring, we developed a complex powder consisting of synthetic mica, titanium dioxide, and aluminum hydroxide. The developed PB powder exhibited similar reflective characteristic to pearl blurring. The BRDF of the powder multilayer structure was similar to BRDF of blurring that was simulated based on the multilayer structure of pearls. Furthermore, the base makeup containing PB powder increased the reflective intensity of the Bio Skin Doll face on the whole. Therefore, based on comparisons of BRDF, specular reflection component, and sensory evaluation, applying this base makeup to Bio Skin Doll embodied the reflective characteristics of the pearly skin image and closely resembled the pearly skin image visually. As such, the optical properties can be claimed to be similar to that of the target pearly skin image. In summary, we formulated a base makeup that can achieve the luster generated by the pearls "blurring" component. This newly developed formulation makes it possible to provide the luster of pearls to human skin.

5. References

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