

Analysis of facial sebum distribution using a digital fluorescent imaging system

Byungkwan Han

Yonsei University
Department of Biomedical Engineering
Wonju, Korea

Byungjo Jung

Yonsei University
Department of Biomedical Engineering
Institute of Medical Engineering
Wonju, Korea

J. Stuart Nelson

University of California–Irvine
Beckman Laser Institute
Irvine, California 92612

Eung-Ho Choi

Yonsei University
Wonju College of Medicine
Department of Dermatology
Wonju, Korea

Abstract. Current methods for analysis of sebum excretion have limitations, such as irreproducible results in repeatable measurements due to the point measurement method, user-dependent artifacts due to contact measurement or qualitative evaluation of the image, and long measurement time. A UV-induced fluorescent digital imaging system is developed to acquire facial images so that the distribution of sebum excretion on the face could be analyzed. The imaging system consists of a constant UV-A light source, digital color camera, and head-positioning device. The system for acquisition of a fluorescent facial image and the image analysis method is described. The imaging modality provides uniform light distribution and presents a discernible color fluorescent image. Valuable parameters of sebum excretion are obtained after image analysis. The imaging system, which provides a noncontact method, is proved to be a useful tool to evaluate the amount and pattern of sebum excretion. When compared to conventional “Wood’s lamp” and “Sebutape” methods that provide similar parameters for sebum excretion, the described method is simpler and more reliable to evaluate the dynamics of sebum excretion in nearly real-time. © 2007 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.2435700]

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1 Introduction

Sebum secreted from sebaceous glands is an oily substance predominantly containing squalene, wax esters, and triglycerides, as well as a small amount of cholesterol esters, and possibly some free cholesterol.¹ The variation of such biological components causes skin disorders related to sebum.² Therefore, the measurement of sebum excretion is important for investigation of the pathophysiology of skin disorders (e.g., acne and some hormonal disorders) and their response to therapy.^{1–4}

The amount of sebum excretion in humans varies individually depending on age,¹ skin type^{5,6} (normal, dry, or oily), and anatomical site (forehead, nose, cheek, or chin) on skin.^{5,6} In the infundibulum, sebum is contaminated with bacterial hydrolases, which convert some of the triglycerides to free fatty acid on the skin surface.^{1,4} A remarkable source of fluorescence on the face are porphyrins produced by bacteria observed within skin pores.⁷ When skin pores are open, they frequently show coral-red fluorescence in normal individuals. However, when skin pores are closed a white or yellow fluorescence is observed depending on the pore condition.⁸ An excess of porphyrins results in intense red fluorescence.^{7,8}

The earliest sebum collection technique was a funnel method using neutral solvent to extract lipid, in which the

collected sebum was evaluated by gravimetry or high-performance thin-layer chromatography and densitometry.^{4,9} In 1944, sebum excretion was first collected noninvasively with filter paper.⁵ Since then, various noninvasive methods have been developed for quantitative evaluation of sebum excretion. In 1958, the “cigarette paper” method was employed to obtain pore patterns and investigate the mechanism of sebum excretion.^{4,10} In 1982, the “bentonite clay” method which is another absorption technique was tried by Downing et al.⁵ Although this method is very cumbersome and time-consuming due to the collection period of at least 12 h, this was generally considered to be an accurate method.^{4,9} Later, the “Sebutape” method using a lipid-absorbing polymeric film was developed to overcome the cumbersome experimental procedures for collection and evaluation of sebum excretion. The “Sebutape” image was analyzed with computer-aided image analysis methods to acquire useful sebum information, such as patterns of follicular sebum excretion, percentage of area covered by sebum, spot density, and maximum and mean areas.^{4,10} Most recently, the “Sebumeter,” which utilizes a photometric technique, was introduced for sebum excretion measurement by providing the amount of sebum in micrograms per square centimeter within a fast sampling period⁴ (~30 s). The “Sebumeter” uses a matted plastic film (64 mm²) for lipid sampling and to measure the increased transparency of a rough film surface after application of lip-

Address all correspondence to Byungjo Jung, Yonsei University, Department of Biomedical Engineering, 234 Maeji, Heungup-myun, Wonju-si, Gangwon-do, 220-710, Korea; Tel: 82-033-760-2786; Fax: 82-33-763-1953; E-mail: bjung@yonsei.ac.kr

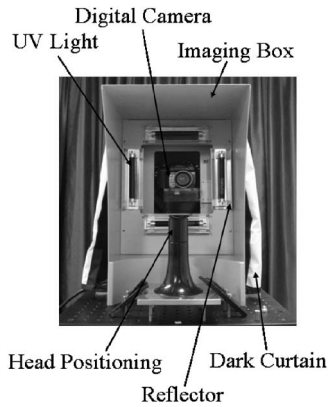


Fig. 1 UV-A induced facial fluorescent imaging system consisting of a color digital camera, four UV-A lamps, and a head-positioning device, which are integrated into an imaging box.

ids. The transparency of the plastic film is measured by a photometric method. The degree of film transparency is expressed on a scale from 0 to 500. Finally, the transparency is converted into the amount of sebum excreted.⁴

The described methods provide regional information on sebum excretion or use off-line analysis methods. Therefore, they are of limited use to determine sebum distribution in real time. The Wood's lamp method, invented in 1903, is an invaluable tool because some biological molecules composed of sebum can be easily detected in broader skin area.⁷ The method uses UV-A (wavelength: 320 to 380 nm) light to induce skin fluorescence in the visible spectral range. Until now, it has been used for only qualitative evaluation of skin condition by taking images or observing skin fluorescence with the naked eye.^{7,11} Therefore, the evaluation of a skin disease/disorder was fairly subjective.

For clinical use, the current methods still have limitations, such as unpredictable results in repeatable measurements due to the point measurement method, user-dependent error due to contact measurement or qualitative evaluation of the image, and long measurement time.⁴ In this paper, we propose an imaging modality for analysis of facial sebum distribution. A UV-induced fluorescent digital imaging system was developed for real-time image acquisition and analysis. The imaging system overcomes several of the aforementioned limitations and artifacts of current methods by easily acquiring a facial fluorescent image. Various image analysis methods are applied to the fluorescent facial image to obtain sebum-related parameters (pattern of follicular sebum excretion, percent of area covered by sebum, number of sebum spots, and mean area and diameter of the spots), which are useful for the evaluation of skin pathology.

2 Materials and Methods

2.1 Imaging System

Figure 1 shows the developed imaging system. Four UV-A lamps, which are also called Wood's lamps or black light, were employed as light sources to induce facial skin fluorescence. A digital color camera was centered between the lamps to provide uniform light distribution on the face. The facial fluorescent image was acquired with a digital color camera

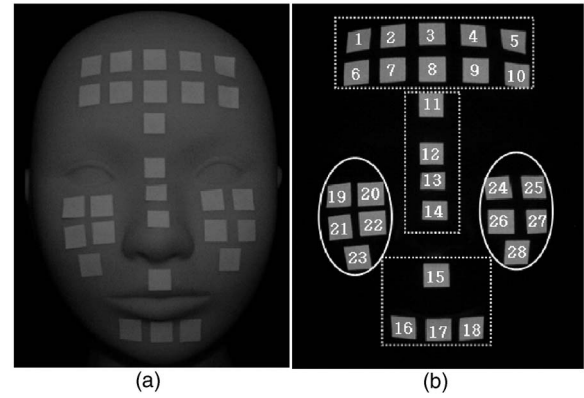


Fig. 2 Investigation of the uniformity of the light distribution. Fluorescent patches were placed on the T-zone (rectangular-dotted lines) and U-zone (solid-elliptical lines) of the mannequin facial model. (a) White light image and (b) fluorescent image of fluorescent patches placed on the mannequin facial model.

(Coolpix 8400, Nikon, Tokyo, Japan) operated in manual mode. This camera was selected because it was able to provide distinct color information in fluorescent images. The camera settings ($F/\#$: 2.9, shutter speed: $1/2$, ISO: 200) were identical for the subject's facial fluorescent images. To ensure optimal facial fluorescent image acquisition, a custom-built head-positioning device was centered between the four UV-A lamps and placed within the working distance (21.6 cm) of the UV-A lamps, resulting in uniform light distribution on the volunteer's face. The entire system was integrated into an imaging box surrounded by a black curtain to provide a dark environment.

2.2 Uniformity of Light Distribution

The spectrum of the UV-A lamp was measured with an optical spectrometer (Triax 550, Horiba, New Jersey, USA) to verify the spectral range and safety of the light source. The uniformity of light distribution on the target area is important for image analysis and accurate comparison of the severity of skin pathology using fluorescent images.¹² Human facial skin was modeled using a mannequin upon which fluorescent patches were placed on the face [Fig. 2(a)]. The light distribution was determined by computing the coefficient of variation (CV) of fluorescent patches in the *T* zone (forehead, nose, and chin) and *U* zone³ (both cheeks). The CV was calculated as follows:

$$CV(\%) = (\sigma/\mu) \times 100, \quad (1)$$

where μ and σ are the mean and standard deviation of the selected fluorescent patches, respectively. A lower CV indicates better uniform light distribution on the face.

2.3 In Vivo Fluorescent Facial Image

A UV-A induced fluorescent image was acquired from a volunteer's head, which was placed on the head-positioning device, and the viewing angle¹² was set to 0 deg with respect to the camera optical axis in order to obtain a frontal facial image. A reference fluorescent patch ($1 \times 1 \text{ cm}^2$) was placed on the volunteer's forehead for area calibration in image analysis.

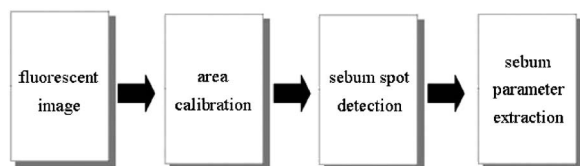


Fig. 3 Schematic diagram of image analysis procedure. The area calibration of the fluorescent image is first performed and sebum spots are basically detected with edge detection algorithm. Finally, various sebum parameters are computed from the processed image using image analysis methods.

An image was first taken and then the volunteer's fluorescent image was acquired without the reference fluorescent patch. The number of pixels (104×104) of the reference fluorescent patch was used for area calibration in image analysis. The UV-A light source power was measured experimentally with a UV solarmeter (Model 5.0, Mat Science Tech Co., Ltd., Seoul, Korea) and determined to be 0.6 mW/cm^2 on the face. The source was illuminated for approximately 3 s, which included the image acquisition time (shutter speed of $1/2 \text{ s}$) and the volunteer's positioning time.

2.4 Image Analysis

The forehead, cheek, and chin area have a relatively planar surface when imaged at the viewing angle of 0 deg . However, the nose area has a curved surface, causing nonuniform illumination, which may cause errors in image analysis, depending on the sebum parameters (for example, sebum pattern) analyzed. In this study, the nose curvature was not considered because such issue can be further minimized by using optimal viewing angle for the area of interest.¹²

Clinically important parameters related to sebum excretion were computed with the image processing procedure illustrated in Fig. 3. The physical area of the acquired fluorescent image was calibrated with the reference fluorescent patch. Sebum spots are detected with a threshold based on a 255 gray-level scale. Finally, various image analysis methods were applied to the processed image to extract sebum parameters. The parameters include the following values:^{3,7,13} percentage of area covered by the sebum spot indicating total sebum output, number of sebum spots indicating secreting sebaceous follicles, patterns of follicular sebum excretion taking into account the number and shape of the sebum spots, and size distribution of spots indicating differences in secretion activity between follicles. Such parameters were automatically computed with laboratory-built "MathLab" codes. Even though the image analysis methods are not described in detail here, they will be provided in a future study.

2.5 Reproducibility Test

UV-A radiation has an effect on sebum excretion when the radiation energy is higher^{14,15} than 20 J/cm^2 . Although UV-A radiation has a total energy of about 1.8 mJ/cm^2 on the face, the reproducibility of the imaging system was performed to evaluate the effect of UV-A radiation on sebum excretion and the efficiency of the image analysis methods. A nonfluorescent patch, which has an open area ($2 \times 2 \text{ cm}^2$) in the center, was placed on a volunteer's forehead. The nonfluorescent patch minimizes operator-dependent error when extracting the

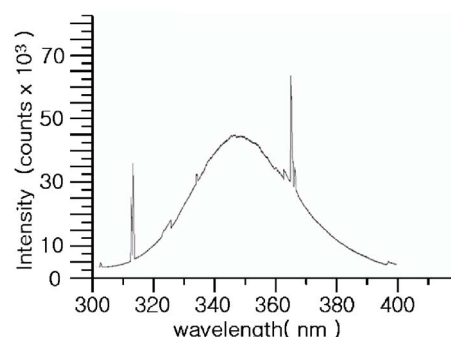


Fig. 4 Optical spectrum (320 to 380 nm) of the UV-A lamp. It has a spectral range that is safe for use on human skin.

identical area and processing the image. Three UV-A-induced fluorescent images were acquired from a volunteer every 10 min. The open area was then analyzed in terms of the pattern and number of sebum spots.

2.6 Comparison with Sebumeter

A statistical correlation analysis was performed to determine the clinical efficacy of the imaging system. The sebum spot densities computed from fluorescent images were compared to those of a Sebumeter, which is a common standard technique. Nine volunteers participated in the experiment and were asked to wash their face 2 h before the experiment. A nonfluorescent patch, which has the same opening area as the Sebumeter measurement area, was attached on the center of the forehead of each volunteer. The fluorescent image was first acquired and then the Sebumeter measurement was performed. Nine data points were acquired from volunteers and used for correlation analysis.

3 Results

3.1 Uniformity of Light Distribution

Figure 4 shows the measured spectrum (320 to 380 nm) of the UV-A lamp used as a light source. It is well known that this spectral range is safe for human skin application. Using the selected camera parameters and light source, the uniformity of the light distribution was investigated by analyzing the intensity distribution of fluorescent patches placed on the mannequin's face. Figures 2(a) and 2(b) show the white light and fluorescent images, respectively, of fluorescent patches placed on the mannequin's face. The camera setting for fluorescent facial imaging was changed to avoid saturation of fluorescent patches. The fluorescent patches representing *T* zone (patch numbers: 1 to 18) and *U* zone (patch numbers: 19 to 28) were sequentially numbered. The intensity distribution on each facial zone is summarized in Table 1. The CV in the *T* zone was slightly higher as compared to that in the *U* zone. However, both zones had a mean error of 4.3% in light distribution, which is negligible for the purposes of our analysis.

3.2 In Vivo Facial Fluorescent Image Analysis

Before taking the fluorescent facial image [Fig. 5(b)], a routine digital color image [Fig. 5(a)] was taken with the same camera using the internal flash while the subject was in the imaging box. Three different facial regions (midforehead,

Table 1 Statistical parameters (mean, standard deviation, coefficient of variation) for light distribution on the mannequin facial model [Fig. 4(b)].

| | Mean | Standard Deviation | CV (%) |
|------------------------------------|--------|--------------------|--------|
| T zone (patch numbers 1 to 18) | 116.33 | 6.44 | 5.54 |
| U zone (patch numbers 19 to 28) | 117.20 | 3.76 | 3.21 |

nose, and midcheek) were clipped from the subject's entire facial fluorescent image to calculate sebum related parameters (the percent area, mean area and diameter, and number of sebum spots). The results are summarized in Table 2. The qualitative information, such as the patterns and the size distribution of the sebum spots, are presented in Fig. 6.

3.3 Reproducibility Test

The upper images in Fig. 7 show three fluorescent images taken from a volunteer. The black area indicates the nonfluorescent path. Using our image analysis method, the pattern of sebum spots were detected as shown in the lower three images of Fig. 7. The detected numbers of sebum spots were respectively 237, 234, and 243 in Figs. 7(a)–7(c). The coefficient of variation (μ , 237.33; σ , 3.51) was 1.8%.

3.4 Comparison with Sebumeter

Figure 8 shows the result of the correlation analysis between the Sebumeter and the fluorescent image. The x axis represents the sebum density measured with Sebumeter and the y axis is the percentage density computed from the fluorescent image. The result appears to be a significant, positive linear correlation ($R=0.81$, $P<0.01$). Hence, the distribution of fluorescing sebum spots is related to the density measurement of sebum spots.

4 Discussion

The T and U zones on the face had slightly different light distributions due to the working distances of the light. The

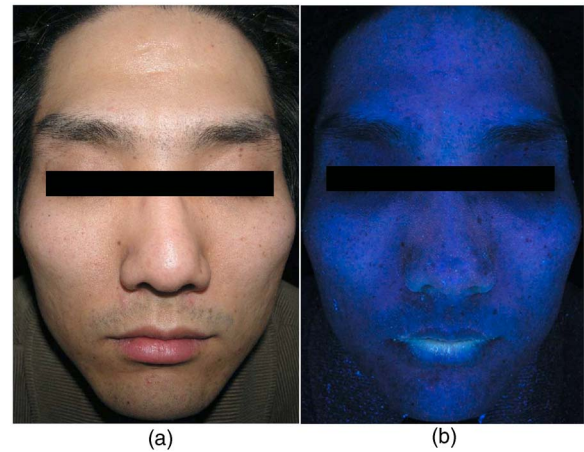


Fig. 5 (a) Routine color image and (b) fluorescent image of a human face. Sun damage blotches are clearly observed in the fluorescent image while they are not discernible in the routine digital color image.

midforehead and nose, which resulted in similar light distributions, are closer to the light source as compared to the midcheek and chin, which resulted in similar light distributions. Such results can affect the fluorescent image analysis because fluorescent intensity is dependent on incident light intensity. Therefore, fluorescent image analysis must be carefully performed when comparing the severity of skin lesions using fluorescent images. In addition, image acquisition conditions, such as camera setting, constant light source, and imaging configuration, must be maintained during the therapeutic period for a constant and reliable comparison of therapeutic outcome for a skin pathology.

Color images have been routinely used in dermatology as an important diagnostic tool to predict therapeutic outcome. However, this has limitations in clinical diagnosis due to poor functional information of the image modality. A fluorescent image [Fig. 5(b)] provides functional information for skin conditions, which cannot be detected in a routine color image [Fig. 5(a)]. The red-, white-, and yellow-colored sebum spots in Figs. 5(b) and 6 are due to excessive skin oil, inflammation,

Table 2 Sebum-related parameters computed from the facial fluorescent image of a human subject (Fig. 6).

| | Midforehead | Nose | Midcheek |
|---|---------------------------|---------------------------|---------------------------|
| Total pixel number | 341 × 353 | 341 × 353 | 341 × 353 |
| Total area (cm ²) | 11.22 (3.3 × 3.4) | 11.22 (3.3 × 3.4) | 11.22 (3.3 × 3.4) |
| Sebum area (cm ²) | 0.2883 | 0.2776 | 0.1096 |
| Percent sebum area (%) | 2.5695 | 2.4741 | 0.9768 |
| Number of sebum spots | 433 | 325 | 226 |
| Mean area of sebum spots (cm ²) | 6.6581 × 10 ⁻⁴ | 8.5415 × 10 ⁻⁴ | 4.8495 × 10 ⁻⁴ |
| Mean diameter of sebum spots (cm) | 0.0291 | 0.0330 | 0.0249 |

and oil that is not pH balanced and may be bacteriostatic, respectively.^{7,8} In addition, sun-damaged areas appear as diffuse gray to black blotches and are clearly observed in the fluorescent image while they are not discernible in the routine digital color image (Fig. 5).

In the analysis of fluorescent image, it is important to determine that the measured signal is caused only by the substances of interest (in this case, sebum) without any influence by other chemical compounds. A good source of interesting artifacts is observed on the lips of volunteers in Fig. 5(b) as a result of foods and drinks the volunteer consumed. Residue from food or drinks on the volunteer's lips might show up on a fluorescent image. In this study, we did not consider such fluorescence because there are no sebaceous glands located on human lips.

The imaging system was proved to have sufficient reproducibility and produced quasi-identical fluorescent images (upper images in Fig. 7). The image analysis method determined that there was an error of less than 2% in the detection of the number of sebum spots. The results show that exposure to UV-A radiation does not influence the sebum excretion during the image acquisition. The errors in determining the number of sebum spots might be further reduced by (1) minimizing the variation of fluorescent image quality due to repositioning and focusing on the volunteer's face and (2) using an optimal threshold value in detecting sebum spots. Such issues will be systematically investigated in future studies. Based on the good reproducibility, we verified the clinical efficacy of the imaging system, which demonstrated good clinical feasibility in the correlation study ($R=0.81$) with the Sebumeter.

In addition to the current application, a fluorescent image can be utilized in clinical diagnoses of various skin lesions. Skin disorders such as hypopigmentation (e.g., vitiligo, tuberous sclerosis, and hypomelanosis of Ito) appear bright blue-white due to autofluorescence of dermal collagen caused by diminished or absent epidermal melanin.⁷ Diagnosis of skin infection related to bacteria (pseudomonas, erythrasma, and propionibacterium acne) and fungus (dermatophytes and tinea versicolor) can be also easily determined.⁷ Other applications include studying the transfer of topically applied medications

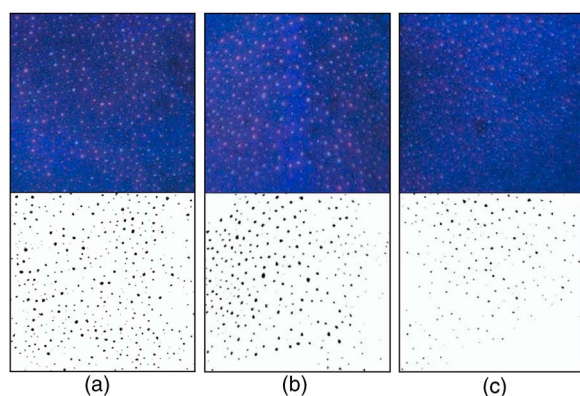


Fig. 6 Fluorescent images (upper) and processed pattern images (lower) of sebum excretion on (a) midforehead, (b) nose, and (c) midcheek. The upper images were used to compute the information on sebum excretion in Table 2.

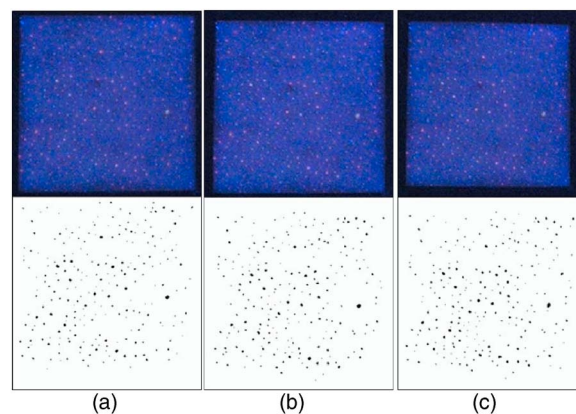


Fig. 7 Reproducibility test of the imaging system. The fluorescent images (upper) were taken every 10 min from a volunteer. The pattern (lower images) and the number of sebum spots were analyzed from the fluorescent images.

to other body sites and monitoring the effectiveness of topical applications such as protective creams.⁷

When compared to conventional methods, our imaging modality is advantageous for continuous monitoring of sebum excretion without damaging the measurement site due to the noncontact method. Another advantage can be attributed to a wider range of imaging which is clinically important for macrolevel observation. When interested in a specific region, a sub-macro-level observation can be accomplished with a digital camera equipped with a higher magnification lens.

The imaging modality when compared to the “Sebutape” method, has the advantage of noncontact image acquisition, nearly real time image analysis, and continuous monitoring of sebum excretion. In addition, the fluorescent imaging method provides information on the sebum parameters (total percent area, density, number, size distribution of sebum spots, and patterns of follicular sebum excretion) for the entire face, while the “Sebutape” presents regional information of about $2.5 \times 2 \text{ cm}^2$. To evaluate sebum excretion, the “Sebutape”

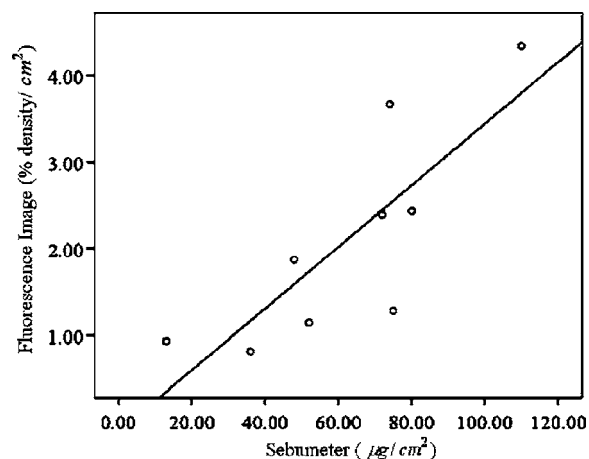


Fig. 8 Linear regression analysis of sebum density. The sebum density on the x axis was measured with Sebumeter and the percentage density on y axis computed from the fluorescent images. The correlation coefficient (R) is 0.81.

method takes approximately 1 h for collection and analysis.¹³ The same parameters (Table 2) acquired from "Sebutape" can be evaluated in nearly real time by applying the image analysis methods to the fluorescent image. For clinical use, the sebum information may play important roles in studying acne because its development is closely related to sebum production.¹⁻³ Morphological patterns of sebum excretion are also useful qualitatively in defining pattern variations over time. For example, Piérard et al. defined five different patterns: infantile, pubertal, adult, acne, and aging.¹⁶ In a future study, the condition of sebum excretion will be classified by fluorescent colors utilizing the color image analysis method. In addition, other skin disorders related to pigmentation and inflammation will be analyzed with various image analysis methods.

5 Conclusions

In conclusion, the fluorescent digital imaging system is a useful, easy, and noncontact method to evaluate sebum excretion and characterize the pattern of sebum distribution. Various image analysis methods were applied to the fluorescent image to obtain parameters for sebum excretion. When compared to conventional methods that provide similar parameters for sebum excretion, our approach is a simpler and more reliable way to evaluate the dynamics of sebum excretion in nearly real time.

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