Received: 31 January 2019 | Accepted: 16 February 2019

DOI: 10.1111/srt.12696

ORIGINAL ARTICLE

WILEY

New image analysis tool for facial pore characterization and assessment

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Funding information
Procter and Gamble

Abstract

Background: Visible facial pores are an important cosmetic concern especially among young females. Number of different methodologies is used today to assess facial pores and efficacy of technologies. Main limitations of these methods are, however, (a) moderate correlation with visual perception, (b) characterization is mostly limited to size or number of pores, (c) measurement is limited to a smaller area of face, and (d) operational difficulties. In order to address these limitations, we developed a 2D image analysis tool to assess and characterize visible facial pores.

Materials and Methods: Two clinical studies were conducted with northeast Asian skin type females. In the first study, 40 subjects age between 20 and 40 with different degree of pore severity were recruited. In the second study, 15 subjects age between 20 and 40 with enlarged pores were recruited to evaluate pore product efficacy. In both studies, full face images were taken using Visia-CR and assessed by means of the newly developed tool and visual grading.

Results: A high correlation between visual grading and pore size was obtained ($r = 0.86$). New methodology was able to differentiate products similar to visual grading.

Conclusion: Novel pore image analysis method using 2D skin surface imaging with standard photography has been developed and validated. In addition to pore size measurements, we propose this method to be used to measure pore shape, color, and orientation for a comprehensive characterization of facial pores.

KEYWORDS

computer vision, facial pores, image analysis, new methods, pore assessment, pore characterization

1 | INTRODUCTION

Image analysis is a widely used method in beauty industry to study facial features and evaluate efficacy of skin care and cosmetic products. It has been applied in wide range of research including measurements of wrinkles,[1] hyperpigmentation,[2] distribution of skin chromophores,[3] skin firmness,[4] and radiance.[5] With the rapid advancement of digital camera sensors[6] over the last decades, 2D surface imaging became more popular in cosmetic science and dermatology research due to (a) high-quality signal which can be analyzed in numerous ways, (b) operational convenience, and (c) affordability.

Enlarged openings of pilosebaceous gland can broadly be considered as pores. They are concentrated in the face and scalp. Visible

facial pores are one of the main concerns among young females, especially in Asia. Number of imaging-based methods has been used in literature to evaluate facial pores in vivo. These include (a) 2D surface imaging (full face imaging[7] or dermoscopic imaging[8]), (b) 3D imaging (in vivo skin[9,10] or skin replica[11]), and (c) confocal laser microscopy.[12] In these methods, pores are numerically evaluated by visual grading and/or image analysis algorithms.

Shaiek[8] et al briefed an image analysis method to measure pores captured using a dermascope. Authors observed a correlation coefficient of 0.75 between pore size evaluated by image analysis and visual grading. This method, however, analyzes a very small area of the face (~15 mm in diameter). One question that needs to be asked is whether a similar correlation can be obtained if relatively larger area of face is graded by visual graders. Pore volume measured by 3D image analysis algorithm was also suggested to correlate moderately high with visual grading among the properties measured.[9,10] Messarra et al[10] and Kim et al.[9] reported moderate correlations (correlation coefficient, *r*, of 0.62 and 0.59 respectively) between pore volume and visual grading using Antera 3D and Primos, respectively.

One typical limitation of the above-mentioned methods is that these methods can measure smaller area of the face which is relatively flat. This approach has number of drawbacks such as (a) Pores in a relatively smaller area may not be representative of the entire face, (b) these methods may not be able to measure pores in geographically restricting areas such as nasal region, and (c) repositioning of the devices to measure the same region pre- and post-treatment is challenging. This is more difficult in chronic clinical trials where repositioning landmarks cannot be drawn. One may use image registration to minimize repositioning error; however, this may reduce the effective area for analysis. In addition, the operation of 3D devices requires higher skills and disciplines to acquire images with good quality since these 3D imaging devices are very sensitive to minor movements of face during image acquisition.

Characterization of pores by the above-mentioned methods is limited to pore number, size, shape, and volume.[7-9] Masaki et al[13] recently, argued that colorimetric features are also important in pore characterization. However, to our knowledge, no objective method has been established to measure color in and around facial pores in vivo.

Due to the above limitations of the current methodologies, visual grading might be still used in clinical trials frequently despite the challenges associated with visual gradings such as (a) lack of specificity in characterization, (b) nonlinear scale, (c) training and qualification, (d) cost, and (e) compliance.

In this article, we propose a novel image analysis method based on 2D full face image to assess and characterize visible facial pores in the attempt of addressing the limitations of current methodologies. Validation results and some key insights related to geometrical and colorimetrical properties of facial pores are also shared.

2 | MATERIALS AND METHODS

2.1 | Subjects

Two separate clinical studies were performed for the validation of the new method.

2.1.1 | Study A for 1st level validation (bare skin)

Human subjects for pore measurements: 40 northeast Asian skin type females residing in Singapore age between 20 to 40 years with various degree of pore visibility (based on a predefined visual scale (Figure 1) covering less-visible pores to very-visible pores) were recruited.

Visual graders: 15 northeast Asian skin type females residing in Singapore age between 20 to 40 years were recruited to grade pores.

2.1.2 | Study B for 2nd level validation (product efficacy)

Human subjects for pore measurements: 15 northeast Asian skin type females residing in Singapore age between 20 to 40 years were recruited.

Visual graders: 15 northeast Asian skin type females residing in Singapore age between 20 to 40 years were recruited to grade pores.

Both studies were conducted in a variable temperature variable humidity facility at the Procter and Gamble in Singapore. A written and witnessed informed consent which explained objectives, risks, and benefits of the study was obtained from each subject upon the enrollment of the study. Prior to take measurements, subjects

FIGURE 1 Pore scale used for visual grading. Scale 1 represents less-visible pores while scale 5 represents more visible pores [Colour figure can be viewed at wileyonlinelibrary.com]

washed their faces with a standardized cleansing method and then acclimated in the facility at 21 ± 1°C and 45 ± 5% relative humidity for 30 minutes.

2.2 | Full face 2D images

Full face 2D images were captured by Visia-CR® imaging system (Canfield Scientific, New Jersey, USA). Visia-CR® is a commercialized clinical imaging device.[7,14] This system consists of a Canon 5D Mark II® DSLR camera equipped with a full-frame CMOS sensor. VISIA-CR® is able to capture entire face area in various light modalities, and in these trials, we used standard 2 (S2) and cross-polarized (XP) modalities. XP image modality captures images using cross-polarization photography technique to remove surface reflection from the image.[15] This image gives accurate color information of the skin, and therefore, we used it to measure color of skin and pores. In contrast, S2 image captures both surface and subsurface reflection and, therefore, we used it for pore segmentation. Images were captured with default settings defined by the manufacturer. Once Visia-CR images were taken in RAW file format, they were converted into TIFF file format using Canon Digital Photo Professional (version 4.4.30.2) developed by Canon Inc.

2.3 | Study A

Both study A and B were done to validate the new method. Study A was a cohort study done at a single time point. Upon arrival to the test facility, subjects cleansed their faces using a standardized cleansing protocol. Visia-CR images were taken after 30 minutes of acclimation.

Visual grading study of pore severity was done using LACIE 526 (LaCie SAS, France) monitors which were color calibrated prior to the study. Full face side images (left and right) captured by Visia-CR were projected, and graders were asked to grade the severity of pores in cheek region using a 5-point scale (1: less visible – 5: more visible) as shown in Figure 1. Images were graded as absolute grading.

2.4 | Study B

Study B was an acute product efficacy trial. Upon arrival to the test facility, subjects cleansed their faces using a standardized cleansing protocol. Baseline Visia-CR images were taken after 30 minutes of acclimation. After the pretreatment imaging, randomly assigned skincare product was applied to one side of the face while the other side was left untreated. The side of treatment was also randomly determined. Three commercialized skincare products were tested: (A) a primer with opacifiers and soft focus powders, (B) an emollient-based mask with clay, and (C) a serum with soft focus powders. These products were chosen because the technologies are thought to provide acute pore visibility reduction. Posttreatment measurements were taken 15 minutes after product application for product A and C. Product B was applied following the manufacturer's instructions and waited 10 minutes before washing it off. Then the measurements were taken after 15 minutes acclimation. Since the

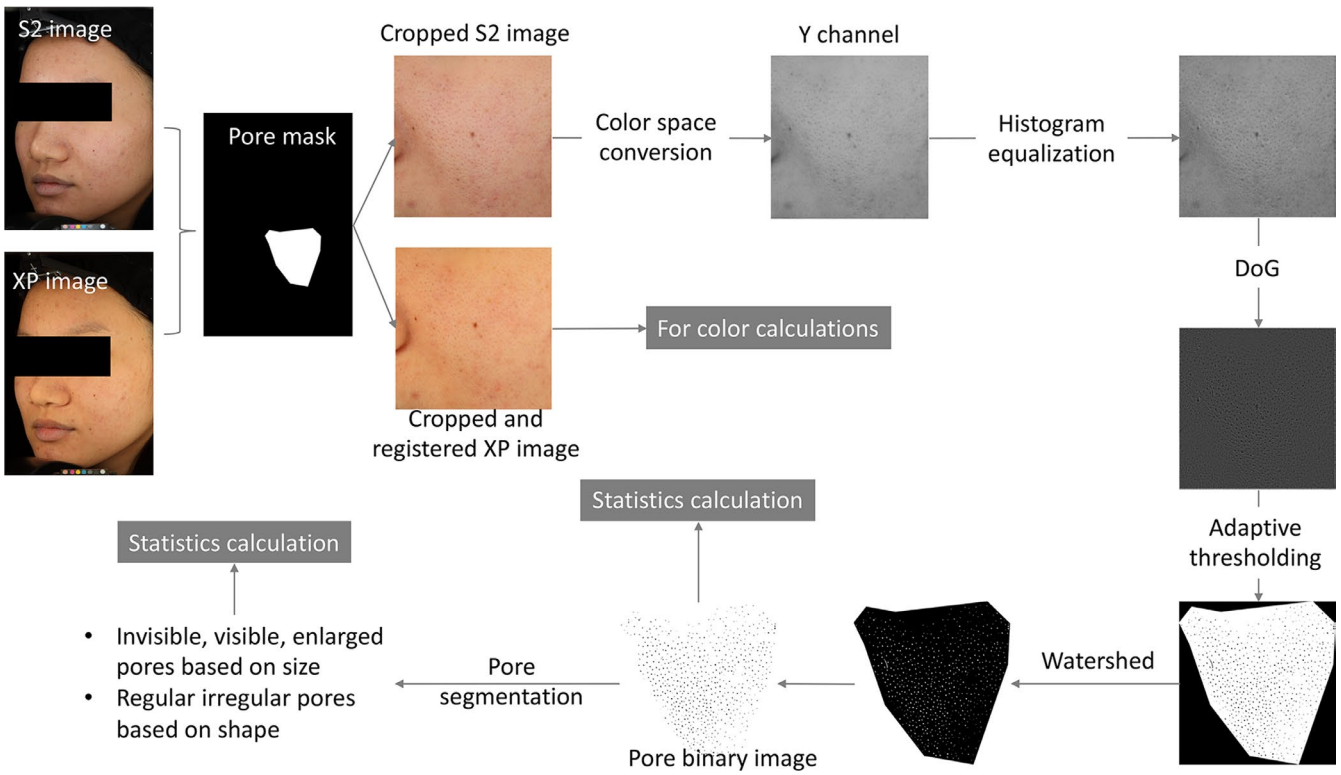

FIGURE 2 Schematic diagram of the pore algorithm showing the key steps. S2 and XP images taken from Visia-CR were used as the input images along with a binary pore mask [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 3 Binary images used for neighborhood color calculation. Size of neighborhood was 10 pixel from boundary of blobs

product properties and application procedures were significantly different and degree and distribution of facial pores were different between panelists, dosage was not controlled but recorded.

A comparative visual grading study of pore severity was done using LACIE 526 (LaCie SAS, France) monitors which were color calibrated prior to the study. Two pictures taken before and after product treatment were projected on the screen in a randomized design. Projected two images were full face left and right side images. Graders compared the severity of the pores in cheek region between two images with an 11 point scale (−5 to + 5).

2.5 | Image analysis algorithm for facial pore features

An image analysis algorithm was developed to segment and quantify pores. Figure 2 is a diagram of critical steps of the newly developed algorithm. Both Visia-CR S2 image and XP image were used as the input along with a binary pore mask (ROI). Since the present work primarily focused on pores in cheek region, a binary mask focusing on cheek was used. As the first step, both S2 and XP images were cropped into pore mask. Cropped S2 RGB image was then converted into YCbCr color space. Luminance channel (Y) was used for further processing.

Due to the geometry of the face and positioning of flashes, achieving uniform illumination across the face is very challenging. Uneven illumination is undesired in feature detection from digital images. We, therefore, adopted contrast-limited adaptive histogram equalization (CLAHE)[16] to improve illumination. In this method, image is divided into a set of tiles and contrast is enhanced for each tile. Bilinear interpolation is used to combine neighboring tiles.[17]

Fine lines, hyperpigmentation spots, uneven tone, facial hair, and so on can be considered as the noise in pore segmentation. We first applied Difference of Gaussian (DoG) filter to remove these noises. DoG filtering has been used in image texture analysis.[18,19] In this method, image is passed through below DoG kernel where x is the distance from the origin in the horizontal axis, and y is the distance from the origin in the vertical axis. σ_1 and σ_2 are the standard deviation of two Gaussian distributions.

$$DoG = \frac{1}{2\pi\sigma_1^2} e^{\left[-\frac{x^2+y^2}{2\sigma_1^2}\right]} - \frac{1}{2\pi\sigma_2^2} e^{\left[-\frac{x^2+y^2}{2\sigma_2^2}\right]}$$

A binary image was then created using adaptive thresholding with binarization.[17] Watershed transformation was then applied to separate connected features. Pore-like features were eventually segmented into a binary image through size/shape filter. Pore binary image was used to calculate pore geometry related statistics such as number, area, circumference, aspect ratio, orientation, and Cartesian coordinates of centroid. A separate binary image was created to measure color around pores (neighborhood color) as shown in Figure 3.

Although XP image and S2 images were taken within seconds, panelists might have minor movements. In order to minimize the effect of these minor moments, XP image was first aligned with S2 image using a rigid intensity-based image registration method.[17] Registered XP image was used to measure color of skin, pores, and neighborhood. All colors were initially measured by RGB intensities which were then converted into CIE-LAB color space, which is the most established color space for skin measurements.

Furthermore, binary pore image was segmented based on the area of pores (mm^2) into invisible ($0.025\ mm^2 < size \leq 0.15\ mm^2$), visible ($0.15\ mm^2 < size \leq 0.25\ mm^2$), enlarged ($0.25\ mm^2 < size \leq 1\ mm^2$). This segmentation was based on segmentation used by Kim et al[9] but further optimized by visually evaluating subjects with different pore severity. Average statistics of these pore classification as well as statistics of each and every pore were saved into text files for further analysis.

Following statistics were measured in this method: (a) pore count, (b) pore area, (c) total pore area, (d) pore area fraction (PAF) (=total pore area/area of Region of Interest), (e) pore shape—measured by aspect ratio (=minor axis length/major axis length), (f) pore orientation (=angle between horizontal line and major axis), (g) pore color, (h) neighborhood color, (i) skin color, and (j) pore color contrast (=contrast between pore and neighborhood using DE2000[20]).

This image analysis algorithm was developed using Matlab R2017a (MathWorks, Inc., Massachusetts, USA).

2.6 | Statistical analysis

R version 3.4.3 was used in statistical analysis.[21] Correlation between image analysis parameters and visual grading was evaluated by Pearson correlation analysis. $P = 0.05$ was used to determine the statistical significance of the correlation. In product efficacy testing, products were compared by Student's t test. $P = 0.05$ was used to determine the statistical significance.

3 | RESULTS

3.1 | Level 1 validation (bare skin)

The objective of this study was to assess the correlation between proposed image analysis method and visual perception. Table 1 shows the correlation coefficient between visual grading and attributes related to pore size we measured using this new method. As can be seen, mean pore size was highly correlated with visual grading. Interestingly, the correlation coefficient of visible PAF was considerably higher than that of enlarged PAF. Pore count also showed a good correlation. As can be seen, all correlations were statistically significant.

Figure 4 shows the regression plot between visual grading and mean pore size. As can be seen, visual grading can be predicted reasonably well with the mean pore size with an R^2 of 0.73.

3.2 | Level 2 validation (product efficacy)

The objective of this study was to assess if efficacy of products evaluated by the new image analysis is similar to that of visual grading. Since Total PAF represents the summation of total pore area relative to the region of interest, we used it for product efficacy evaluation by image analysis.

Formula 1 was used to evaluate product efficacy by image analysis while formula 2 was used to evaluate product efficacy by visual grading.

Formula 1:

$$\textit{Product efficacy using image analysis} = \left[PAF_{\textit{posttreatment treated side}} - PAF_{\textit{pretreatment treated side}}\right] - \left[PAF_{\textit{posttreatment untreated side}} - PAF_{\textit{pretreatment untreated side}}\right]$$

TABLE 1 Correlation coefficient and P-value between image analysis parameters and visual grading

Parameter	Correlation coefficient	P-value
Mean pore size (area)	0.86	2.17E-12
Visible PAF	0.78	3.78E-09
Total PAF	0.73	8.91E-08
Invisible PAF	0.66	3.19E-06
Pore count	0.65	6.61E-06
Enlarged PAF	0.58	9.71E-05

PAF = total pore area/area of region of interest.

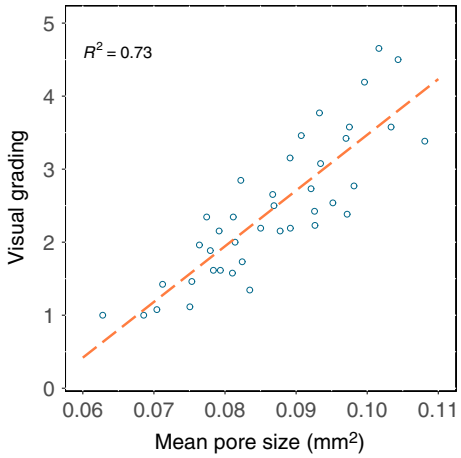

FIGURE 4 Linear regression plot between pore size and visual grading [Colour figure can be viewed at wileyonlinelibrary.com]

Formula 2:

$$\textit{Product efficacy using visual perception} = \textit{Comparative visual perception read}_{\textit{treated side}} - \textit{Comparative visual perception read}_{\textit{untreated side}}$$

Figure 5 shows the efficacy evaluated by both visual grading and image analysis methods. As shown in Figure 5A, visual grading method shows that product A was significantly reduced pore appearance as compared to product B and C. This result was expected as product A contains both opacifiers and soft focus powders compared to the other products.

Product B and C were parity. A similar conclusion was reached by PAF results from image analysis suggesting that new methods have the same sensitivity in terms of product differentiation as the visual grading method as shown in Figure 5B.

In summary, above results validate the image analysis method we developed to analyze facial pores as well as evaluate efficacy of technologies targeting facial pores.

4 | DISCUSSION

In this paper, we have introduced a novel image analysis method to assess and characterize visible facial pores. This method addresses number of limitations of current methodologies used in clinical trials. First, we demonstrated superior correlations with visual perception. We implemented contrast-limited adaptive histogram equalization (CLAHE) to enhance the illumination and contrast to reduce the impact of uneven illumination due to geometry of the face and positioning of flashes/camera. Figure 6 shows impact of CLAHE on cheek pore segmentation. CLAHE dramatically improved pore segmentation.

By using difference of Gaussian (DoG) filter along with size/shape filters, we were able to segment pores reasonably well to achieve significantly higher correlations with visual grading compared to previously disclosed methodologies. We further proved that visual

grading can be predicted with an R^2 of 0.73 which is superior to the established methods.

Correlation of pore area fraction (PAF) and visual grading vs that of average pore size and visual grading was slightly lower. However, since PAF takes the summation of all pores, we recommend PAF to be used for product efficacy evaluation. Some of the previous studies on pore methodologies did not attempt to correlate product efficacy measured by instrumental methods with that measured by visual grading. In contrast, this paper proved that our method is able to differentiate products in par with visual grading providing robust evidence of method qualification. These findings validate the method to be used in place of visual grading in pore studies and product efficacy evaluation.

It is to be however noted that the validation of this algorithm was done using cheek since significant higher pore density can be observed in cheek region for majority of the study panel. Nevertheless, this method can be applied on other regions of the face, for example, (a) nasal region as shown in Figure 7 or (b) even full face. This is a significant advantage compared to 2D dermoscopes imaging, 3D imaging, and confocal laser microscope which are often limited to easily accessible regions. This is the second advantage of this methodology.

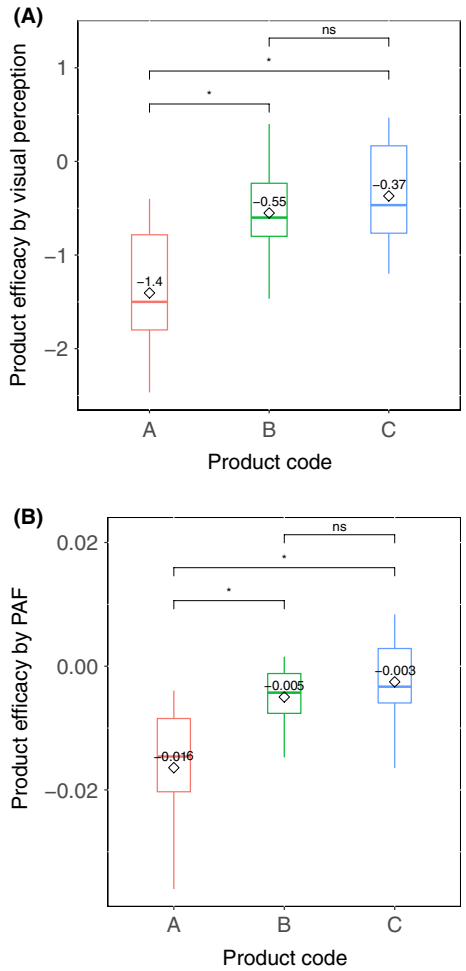

FIGURE 5 Product efficacy comparison by (A) visual perception method and (B) image analysis using PAF. *indicates statistical significance at $P = 0.05$ [Colour figure can be viewed at wileyonlinelibrary.com]

Third advantage of this method is the ability to characterize different properties of pores. This method further enables researchers to measure color of pores, color around pores, and color contrast of pores. Figure 8 shows cheek region of two panelists having significant color contrast differences. As shown, panelist in Figure 8A has more visible pores compared to the other panelist. She (Figure 8A) has 78% darker pores compared to the other panelist (Figure 8B) although her pores are only 25% larger in area. This method therefore makes it possible to differentiate pore severity not only based on size but also based on color.

Masaki et al[13] recently argued that carbonylated proteins may contribute to the darkening of pores. With the new methodology disclosed in this paper, we are now able to further investigate pore darkening phenomena.

Figure 9 shows elongated and round pores of two different panelists. As can be seen, the shape difference and orientation difference are noticeable. Importantly, pore shape and orientation measured by our method are in-line with the visual observation. This enables us quantitatively characterize pore shape and orientation. Decrease in elasticity is associated with pore count hence pore development.[22] Sugata et al[12] reported that undulating structure of epidermal-dermal junction (stalagmite-like structure) is associated with enlarged pores. Therefore, it is hypothesized that the skin structure around pores is associated with pore enlargement. Consequently, one can assume that the effect of the skin structure around pores not only affect the size of the pores but also the shape and orientation. Measurement of pore shape and orientation can, therefore, be considered to be critical in any comprehensive pore study.

Finally, since this method essentially a 2D image analysis method, this can easily be implemented in clinical trials without the need of additional hardware. Moreover, this approach has very high system portability enabling analysis of 2D images captured from different sources ranging from clinical imaging devices to mobile phones. If the imaging device does not provide cross-polarized images (eg, mobile phones), alternative approaches such as measurement of apparent color using standard picture can be implemented for color measurements.

Despite its ability to characterize geometrical and colorimetrical properties of visible facial pores, this method cannot be used to estimate pore depth or volume. This is a key limitation of this 2D surface image-based method.

5 | CONCLUSION

A novel image analysis method was developed and validated to characterize facial pores and evaluate treatment efficacy. Mean pore size highly correlated with visual perception (correlation coefficient, $r = 0.86$). This method is able to measure pore color, shape, and orientation in addition to size and count enabling holistic study of facial pores. Future research can be focused on (a) comprehensive pore

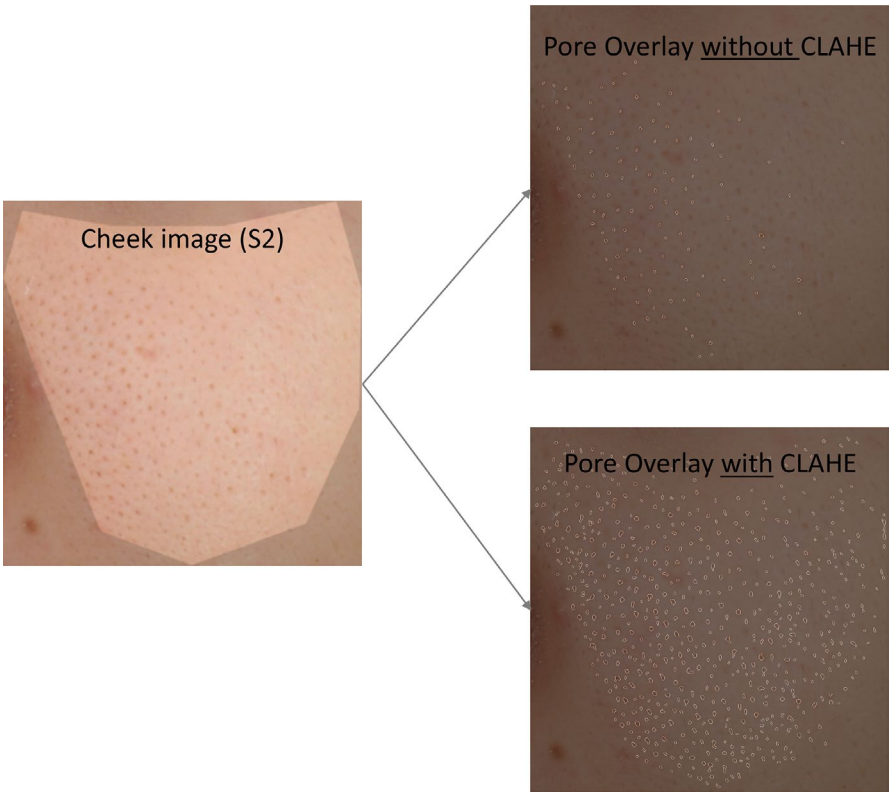

FIGURE 6 Pore segmentation was improved with contrast-limited adaptive histogram equalization (CLAHE) [Colour figure can be viewed at wileyonlinelibrary.com]

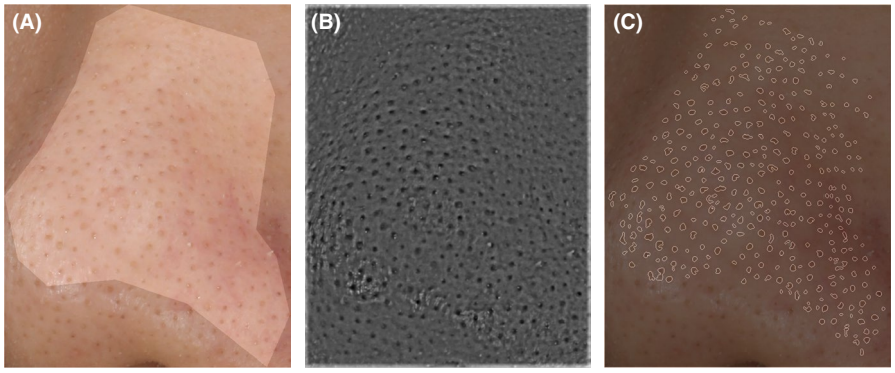

FIGURE 7 Pores in nasal region can be segmented well with the proposed method (A) Nasal region with enlarged pores. Region of interest is highlighted. (B) enhanced image with DoG and (C) Pore overlay [Colour figure can be viewed at wileyonlinelibrary.com]

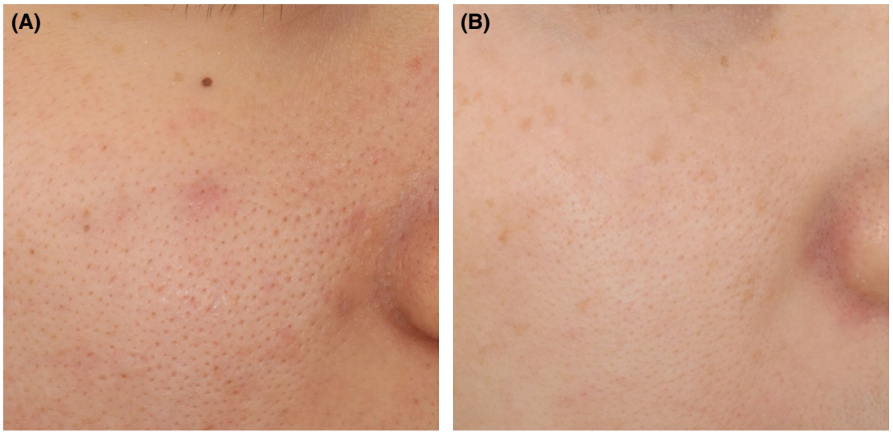

FIGURE 8 Significance of pore color contrast in pore visibility (A) a panelist with darker pores in cheek. Mean color contrast = 2.5, pore count = 462, mean pore size = 0.10mm^2; (B) a panelist with lighter pores in cheek. Mean color contrast = 1.4, pore count = 414, mean pore size = 0.08 mm^2 [Colour figure can be viewed at wileyonlinelibrary.com]

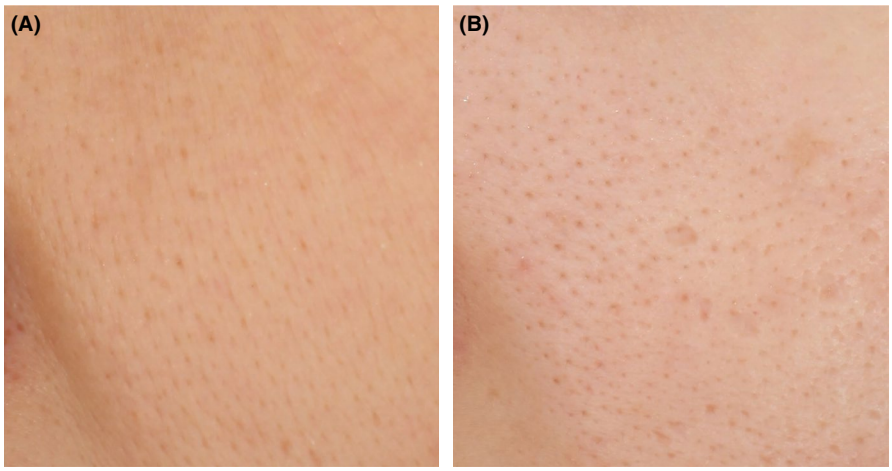

FIGURE 9 Significance of pore shape (A) a panelist with elongated pores in cheek. Mean aspect ratio = 0.55, mean orientation = 61°, (B) a panelist with round pores in cheek. Mean aspect ratio = 0.69, mean orientation = 39° [Colour figure can be viewed at wileyonlinelibrary.com]

characterization especially with aging, (b) establish the root cause of pore darkening, and (c) development of novel treatment options.

ACKNOWLEDGEMENT

This research was funded by the Procter and Gamble Company.

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REFERENCES

1. Hamer MA, Jacobs LC, Lall JS, et al. Validation of image analysis techniques to measure skin aging features from facial photographs. *Skin Res Technol*. 2015;21:392-402.
2. Miyamoto K, Takiwaki H, Hillebrand GG, Arase S. Development of a digital imaging system for objective measurement of hyperpigmented spots on the face. *Skin Res Technol*. 2002;8:227-235.
3. Matts PJ, Dykes PJ, Marks R. The distribution of melanin in skin determined in vivo. *Br J Dermatol*. 2007;156(4):620-628.
4. Miyamoto K, Nagasawa H, Inoue Y, Nakaoka K, Hirano A, Kawada A. Development of new imaging methodology and system for the rapid and quantitative evaluation of the visual appearance of facial skin firmness. *Skin Res Technol*. 2013;19:e525-e531.
5. Matsubara A, Liang Z, Sato Y, Uchikawa K. Analysis of human perception of facial skin radiance by means of image histogram parameters of surface and subsurface reflections from the skin. *Skin Res Technol*. 2012;18:265-271.
6. Gouveia LCP, Choubey B. Advances on CMOS image sensors. *Sensor Review*. 2016;36:231-239.
7. Jang SI, Kim EJ, Lee HK. A method of evaluating facial pores using optical 2D images and analysis of age-dependent changes in facial pores in Koreans. *Skin Res Technol*. 2018;24(2):304-308.
8. Shaiek A, Flament F, François G, et al. A new tool to quantify the geometrical characteristics of facial skin pores. Changes with age and a making-up procedure in Caucasian women. *Skin Res Technol*. 2017;23(2):249-257.
9. Kim SJ, Shin MK, Back JH, Koh JS. Pore volume is most highly correlated with the visual assessment of skin pores. *Skin Res Technol*. 2014;20(4):429-434.
10. Messaraa C, Metois A, Walsh M, et al. Antera 3D capabilities for pore measurements. *Skin Res Technol*. 2018;24(4):606-613.
11. Sugiyama-Nakagiri Y, Sugata K, Hachiya A, Osanai O, Ohuchi A, Kitahara T. Ethnic differences in the structural properties of facial skin. *J Dermatol Sci*. 2009;53(2):135-139.
12. Sugata K, Nishijima T, Kitahara T, Takema Y. Confocal laser microscopic imaging of conspicuous facial pores in vivo: relation between the appearance and the internal structure of skin. *Skin Res Technol*. 2008;14(2):208-212.
13. Masaki H, Mizutani T, Ogawa N, Suzuki H, Okano Y, Akita H. Carbonylated proteins contribute to the darkness around facial pores. *J Dermatol Sci*. 2018;89(3):299-301.
14. Ma L, Tan Y, Zheng S, et al. Correlation study between image features and mechanical properties of Han Chinese facial skin. *Int J Cosmet Sci*. 2016;39(1):93-100.
15. Anderson RR. Polarized Light Examination and Photography of the Skin. *Arch Dermato*. 1991;127(7):1003-1005.
16. Zuiderveld K. Contrast limited adaptive histograph equalization. In: Heckbert, PS, ed. *Graphic Gems IV*. San Diego: Academic Press; 1994:474-485.
17. MathWorks. Image Processing Toolbox: User's Guide (R2017a).
18. Giordano D, Leonardi R, Maiorana F, Scarciofalo G, Spampinato C. Epiphysis and metaphysis extraction and classification by adaptive thresholding and DoG filtering for automated skeletal bone age analysis. *Conf Proc IEEE Eng Med Biol Soc*. 2007;2007:6551-6556.
19. Schönholzer F, Hahn D, Zarda B, Zeyer J. Automated image analysis and in situ hybridization as tools to study bacterial populations in food resources, gut and cast of Lumbricus terrestris L. *J Microbiol Methods*. 2002;48:53-68.
20. Habekost M. Color difference equations and the human eye. In: TAGA 59th Annual Technical Conference. Pittsburg; 2007:291-310.
21. R Core Team. *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing; 2017.
22. Kim B, Choi J, Park K, Youn S. Sebum, acne, skin elasticity, and gender difference - which is the major influencing factor for facial pores? *Skin Res Technol*. 2013;19(1):e45-e53.

How to cite this article: Dissanayake B, Miyamoto K, Purwar A, Chye R, Matsubara A. New image analysis tool for facial pore characterization and assessment. *Skin Res Technol*. 2019;25:631–638. https://doi.org/10.1111/srt.12696