Quantification of Facial Pores Using Image Analysis

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A common complaint related to aging in women concerns the widening of facial pores. To evaluate the severity of the phenomenon, the authors developed a device called Dermascore that enables pores to be visualized, photographed, and evaluated with an associated scale. Quantitative evaluation was performed on the pictures using a specific image analysis algorithm that allows the number and size of pores to be measured. The purpose of the study was to validate evaluation through image analysis in comparison with visual evaluation. Dermascore photographs of the cheek were taken of 150 women aged 18 to 70 years and evaluated by an expert panel with the grading scale used in standardized conditions. The relationship between the scores and the computed results was studied using linear regression analysis followed by a Pearson product moment correlation. The algorithm allows the selection of pores whose diameter was more than a chosen threshold value. When the threshold is 100 µm, 250 µm, and 500 µm, the correlation coefficient between visual evaluation and calculated pore size was respectively 0.66, 0.76, and 0.60. The image analysis procedure evaluated the size of facial pores independently of their number, and the most relevant threshold value is 250 µm to better fit the experts' judgment.

As described by Uhoda et al,[1] pores are outlets to sebaceous glands found on the skin's surface that secrete oil to lubricate and protect the skin. Pores appear as empty funnel-shaped structures and are found in the skin of all individuals, except in the palms and soles.

Trouble with sebaceous gland function can induce abnormal conditions such as comedones, pimples, and acne.[2] A well-known consequence from a high rate of sebum secretion at the skin's surface is oiliness. To date, the factors that affect the appearance of pores and the role of aging in the enlargement of pores remain relatively unknown.

Previous studies have suggested a link between excessive sebum secretion and enlarged pores.[3-5] Various factors are known to influence sebum secretion, which seems to decrease with increasing age.[6-8] It was reported that sebum secretion peaked approximately at age 20 years and then steadily declined in both men and women until the end of life.[9] Hormonal factors also contribute to differences in sebum secretion.[7] Environmental factors, such as temperature and humidity, are known to

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influence sebum secretion[10]; however, few papers describe the determination of pore size. Various treatments have been proposed to reduce the size of pores; however, due to the lack of appropriate methods for quantitative evaluation, it is difficult to assess their efficacy.[5]

To evaluate the severity of pore size enlargement, the authors developed the Dermascore device. Dermascore is equipped with appropriate polarizing filters that enable a visual assessment to be made and photographs of the skin to be taken. Specific software, image analysis algorithm developed under LabVIEW, was designed to measure the number and size of pores within the Dermascore observation area. The purpose of this study was to validate the image analysis procedure and compare it with visual score evaluation.

MATERIALS AND METHODS

Study Group and Controlled Conditions

A panel of 150 female participants aged 18 to 70 years was recruited. Selection criteria did not include any restrictions regarding skin type. The study was carried out in a room with a controlled temperature of 23°C and relative humidity of 39%. All measurements of the participants were performed after an acclimatization period in the controlled room for 20 minutes. Photographs were taken of the cheek where pores are most visible.[11]

Expert Panel

The experts were recruited according to their good visual sensitivity, which was evaluated by ophthalmologic tests. They took part in a training period to learn to evaluate objective criteria with a precise definition. Before enrollment, they were selected according to their capacity to discriminate and their reproducibility (intrasession and intersession) after repeated evaluations of 400 photographs (350 photographs and 50 duplications).

The expert notation was accepted if the reproducibility, measured by the average deviation on the set of 150 photographs evaluated twice, was less than 10% of the range of the reference chart (minimum grade=5). This validation process is well described in the Association Française de Normalisation International Standards Organization, which deals with certification and represents France within European and international standardization authorities.[12]

A panel of 11 experts was used to examine the photographs of the participants' cheeks and grade the pores according to a facial pore chart (Figure 1). The chart was previously constituted from a panel of 220 white women aged 18 to 70 years old.[13] The methodology to build this reference chart is fully described in the reference.[14] The photographs were shown to the experts on a computer screen in random order, which were different for each expert. The photographs

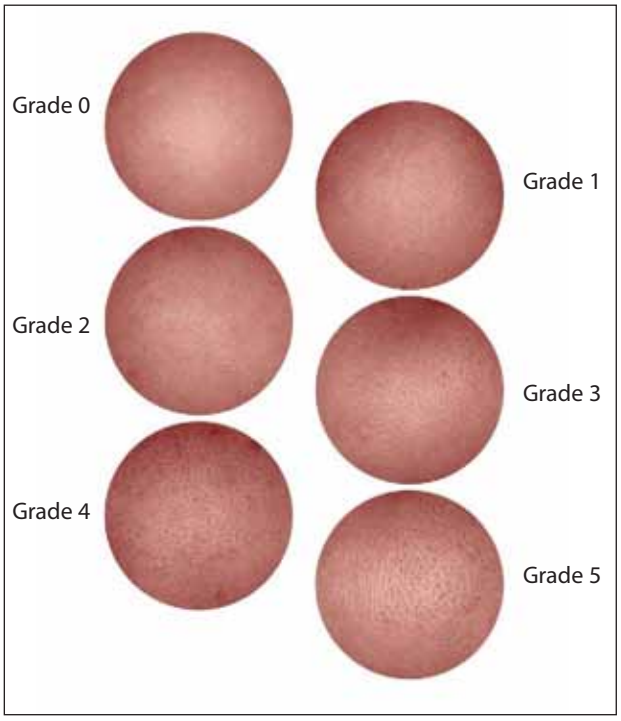


Figure 1. A 6-grade facial pore chart (reference chart) used by the expert panel.

to be graded were obtained from the Dermascore device developed by L'Oréal Research Laboratories.

Pore Size Analysis

Dermascore—This device uses the polarization properties of light to deliver different information as described below.[13,15,16] A beam of light impacting the skin's surface is in part reflected by the surface at a specular angle and transmitted inside the tissue. When the skin is struck by polarized white light, some of the light is reflected and remains white and polarized, whereas the transmitted light becomes depolarized while traveling through the skin's surface. The device takes advantage of this behavior to observe the skin differently. The color aspect alone is observed by removing the specular component with a cross-polarized analyzer, whereas the texture visibility is strengthened by increasing the proportion of specular reflection with a parallel polarized analyzer.

The unique feature of the device allows the skin's color and texture to be observed by simply changing the relative position of the polarizers. The main body of the device, the Dermogenius, is currently available commercially and possesses 6 light-emitting diodes on a ring. The first polarizer covering the ring polarizes the light. The second polarizer is placed on the eyepiece for analyzing the light reflected by the skin. The choice of the parameter to be graded (tone or texture) is selected by a

Figure 2. User interface of image analysis software for analyzing pore size.

rotating polarizer, with a magnification of ×4. The handle contains rechargeable batteries, and the eyepiece can be replaced by a digital camera to obtain photographs of the observed area.

Image Analysis Software—The image analysis algorithm (Figure 2) was developed using LabVIEW 8.0 based on the fact that visible pores are included in high frequency.[17] It is completely automated and does not require any human handling.

Process

Color adjustment of the photographs is performed and the images transformed into a gray scale (Figures 3A and 3B) because the luminance information is the most relevant criteria to fit the human perception of texture due to pores under the Dermascore illumination. Low-frequency data are filtered out in order to focus only on the high-frequency data (Figure 3C). The positioning of a region of interest (ROI) in the center of the photograph (70% of the radius) is automatic. The automatic detection of the ROI enables measurements to be made in millimeters, taking into account the possible differences of magnification between photographs. The size and location of the ROI is matched to the area where the experts evaluated the pore size. Further binarisation and filtering of the image is performed (Figure 3D). Geometric filtering (size and circularity) is used to select the most relevant features corresponding to the actual pores (Figure 3E). The upper threshold for circularity parameter was set to 10 in order to remove features such as hair or fine lines.

The threshold for pore size (minimum diameter for a pore in µm) can be set before the analysis. To determine the best size setting, 3 values were used in this study: (1) 100 µm, because it corresponds to the size of the smallest pore the human eye can see in Dermascore photographs (linked to the magnification of Dermascore and image resolution); (2) 250 µm, which is approximately the size of the smallest pore the experts could effectively see, calculated in the experimental conditions of observation (limited by the density of the pixels); (3) 500 µm, which is approximately the size of the pores that could be observed directly on the face in normal conditions of observation (eg, nonspecific laboratory conditions of

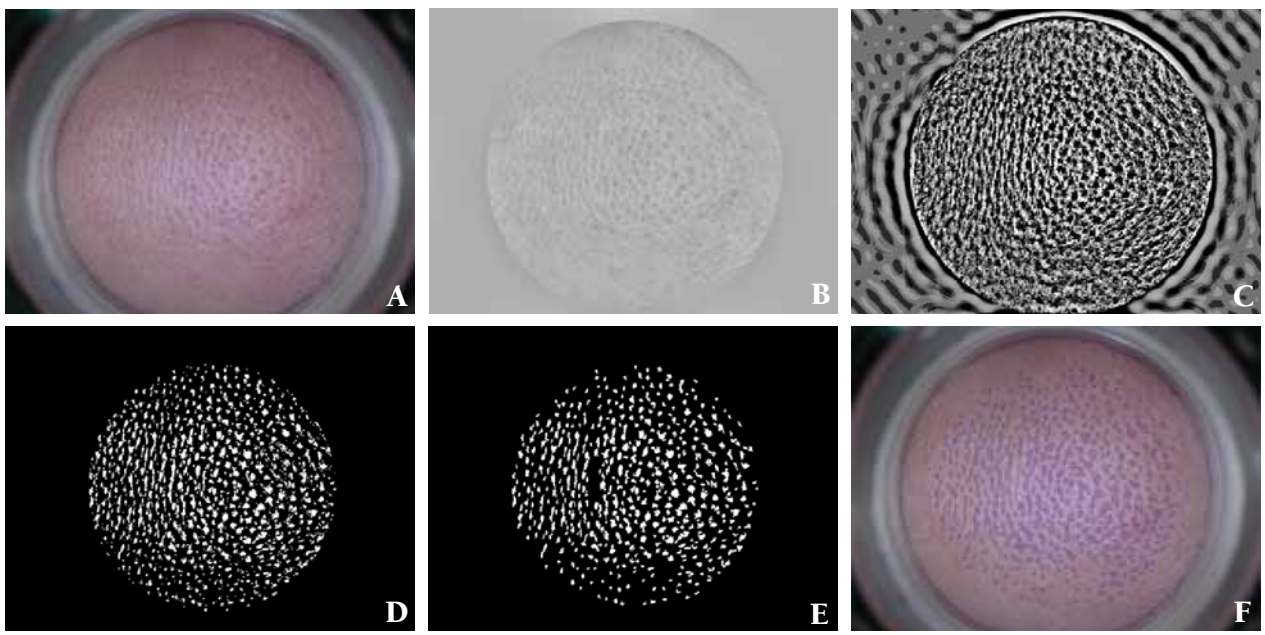


Figure 3. Image analysis software for analyzing pores, depicting source color image (A), gray level image (B), high-frequency image (C), binarised image after morphologic operations (D), image after final geometric filtering (E), and color image with detected pores (F).

TABLE 1

Classification of Expert Panel Values into 5 Groups

Group	1	2	3	4	5
Scores	0.5 . ≤1.49	1.5 . ≤2.49	2.5 . ≤3.49	3.5 . ≤4.49	4.5 . ≤5.49

illumination, various contrasts of pores, longer distance of observation).

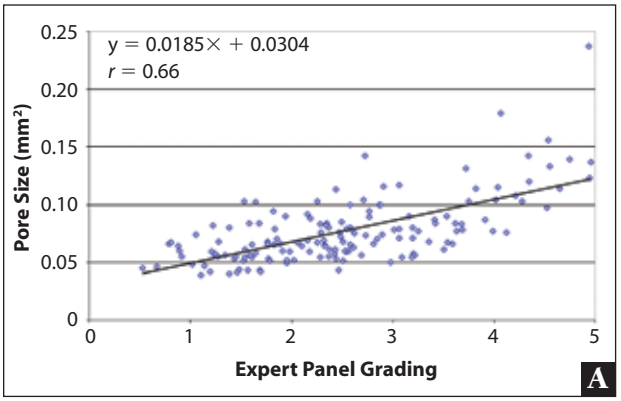
Final selection of real pores is made by colorimetric contrast filtering with the surrounding skin as a method to discard objects such as small spots. Results include a display of detected pores on the initial color image (Figure 3F) and a report of results (size and number of pores per cm^2) on a datasheet that can be further analyzed.

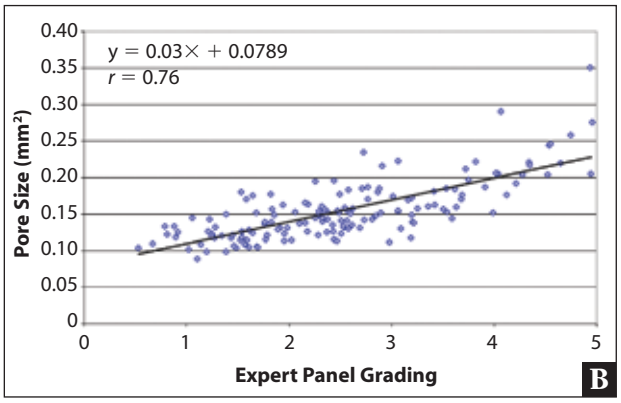
Statistics

The Pearson product moment correlation (SPSS version 13) was used to explore the relationship between data obtained by image analysis approach (size and number), visual evaluation using the pore chart (reference chart), and the correlation between pore size and age.

In order to evaluate the sensitivity of the image analysis approach, the values from the expert panel were classified into 5 groups corresponding with grades 1 to 5 in the reference chart. No score was lower than 0.5, which explains the absence of group 0. Mean pore size and pore density were calculated by image analysis software and a one-way variance analysis was used to compare groups. Groups were defined as described in Table 1.

In order to evaluate the influence of aging on the size of pores, the authors calculated the mean pore size for age classes in years (<30; 30–39; 40–49; 50–59; >60).





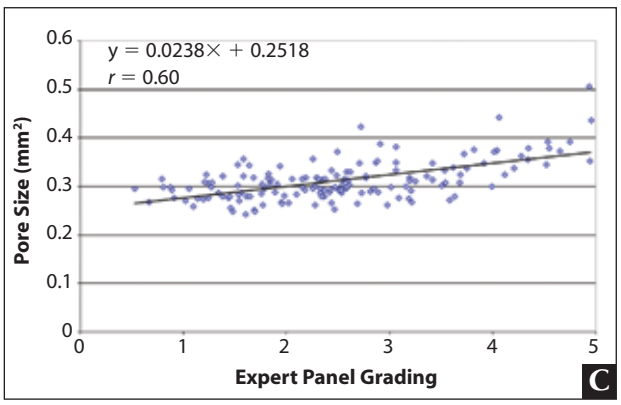


Figure 4. Pore size measured by image analysis versus expert panel grading, with thresholds of 100 µm (A), 250 µm (B), and 500 µm (C).

RESULTS

Figure 4 shows the pore size values calculated by image analysis for the 100-µm, 250-µm, and 500-µm threshold versus the mean grade given by the experts. The statistical results show that the algorithm approach is well correlated with expert panel grading for each threshold value, with a better correlation coefficient (0.76) for the value of 250 µm, 0.66 for 100 µm, and 0.60 for 500 µm.

The mean and statistical differences obtained for each grade with the 250-µm threshold are shown in Figure 5. As expected, an increase in pore size is found when the grade increases. The results of variance analysis show that all groups can be separated except grade 2, which cannot be distinguished from groups 1 and 3. Different groups can be characterized by the criteria of pore size.

Figure 6 shows the mean pore size and number of pores measured for each threshold (100 µm, 250 µm, and 500 µm).

Figure 7 shows the densities of the pores (number of pores per cm^2) obtained by the algorithm for the 3 different values versus the mean grade given by the experts. There is no correlation between density and expert grading for the threshold value of 250 µm (r=0.03), whereas the correlation coefficient for the 100-µm threshold is −0.49 and the correlation coefficient for 500 µm is 0.74.

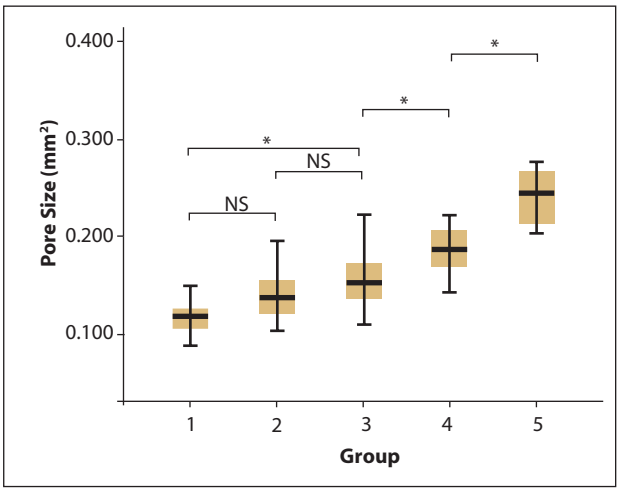


Figure 5. Mean pore size (mm²) measured by image analysis software for each group, with a 250-µm threshold. Asterisk indicates significant differences at $P<.05$ level; NS, no statistical differences between groups.

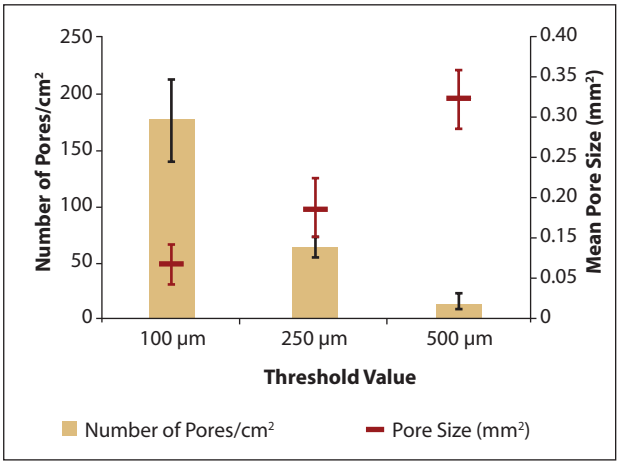


Figure 6. Size and number of detected pores (mean calculated on all the images) versus threshold value.

Table 2 summarizes the correlation coefficients obtained between pore size, the number of pores, and the 2 methods at the 3 tested sizes.

Figure 8 represents pore size versus age and shows no correlation between both parameters. In Figure 9, the mean pore size is very similar, with a maximum in the 50s.

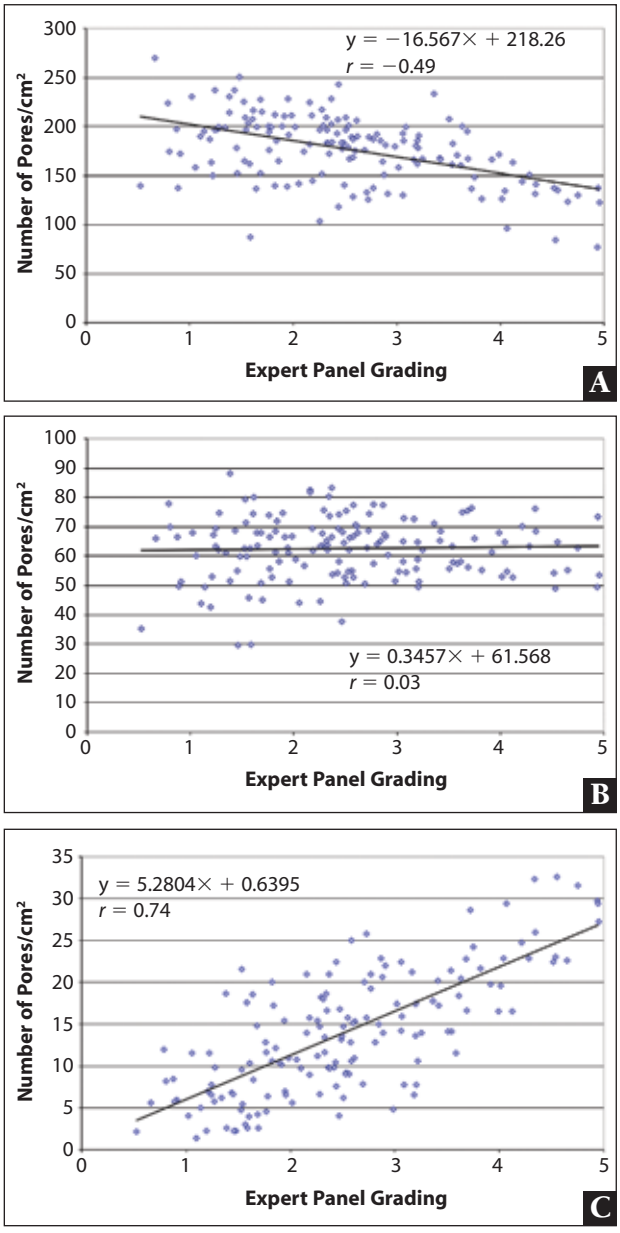


Figure 7. Number of pores per cm² detected by the algorithm versus expert panel grading, with thresholds of 100 µm (A), 250 µm (B), and 500 µm (C).

DISCUSSION

Pores are a vital part of the skin's structure, making it possible for oil glands underneath to protect and hydrate the skin. Though essential, pores can also prevent a person from having beautiful, flawless skin. Large, prominent facial pores tend to first appear during puberty to accommodate the increased production of oil by the glands under the skin. Pores can also become enlarged when they are infected or clogged with dirt, bacteria, and oil. In addition to puberty and infection, genes and age may also produce large facial pores. Individuals with thick skin tend to display more obvious pores, and older people are more vulnerable to having their pores become dilated beyond the normal size.

To date, only a few papers have described objective quantitative methods for evaluating pore size. One can note the 3-dimensional stereo image optical topometer,[5,18] skin capacitance imaging by Lévêque et al,[19] or analysis with a dermoscopic video camera by Roh.[3]

The authors developed a new method of measurement of pore size, based on the analysis of Dermascore

TABLE 2

Linear Regression and Pearson Test Results

Threshold for pore diameter	100 µm	250 µm	500 µm
Pore size, mm^2	0.66	0.76	0.60
Number of pores/cm^2	−0.49	0.03	0.74

photographs. The aim of the present study is to validate this algorithm.

The statistical results (Figures 4 and 5) show that the algorithm approach is well correlated with the current gold standard (correlation coefficient is 0.76 with a 250-µm threshold) and provides a reliable way to get an objective, reproducible quantification of pore size. The results of this study support the validation of this method.

A few points were higher than the regression line (Figure 4B), which explains why the correlation coefficient was not higher than 0.76. This is likely due to the photographs being slightly out of focus. Indeed, the algorithm calculates exaggerated values, whereas the experts correct for the lack of focus in their notation.

It was also noted that the participants' photographs depicting the largest pores were far from the regression curve. This raises the issue of the relevance of the upper limit of the pore chart, which may prompt experts to give a lower score than they would intend to.

Though the correlation with expert evaluation is not perfect, this tool is very useful because it provides rapid results and affords thoroughly objective image analysis.

When the threshold decreases, the number of pores detected increases (Figure 6). For the lower value (100 µm), the correlation coefficient between pore density and expert judgment is negative (Figure 7 and Table 2; r=-0.49), showing that the experts do not use pores of this size range in their evaluation.

On the contrary, with a threshold of 500 µm, the coefficient correlation for size is good (r=0.6), but pore size is highly correlated with pore density in this range of diameter (r=0.79). Furthermore we know that the density of sebaceous follicles is constant with age[20]; therefore, the threshold the authors chose has to be independent of the number of detected pores.

The 250-µm threshold value gives results that better fit the expert judgment (r=0.76) and also provides data completely independent from pore density (r=0.03).

The correlation coefficient between pore size calculated with the 250-µm threshold and the 500-µm threshold is r=0.92. This shows that the choice of 250 µm is not only relevant to fit the expert judgment, but also proves that experimental conditions of observation in this study are close to everyday conditions, simulated by the 500-µm threshold. The 250-µm threshold could be considered as a relevant value to fit the perception of pores in normal conditions.

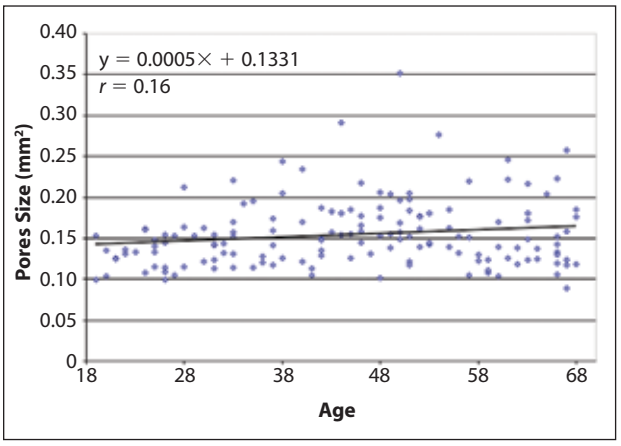


Figure 8. Pore size measured with the algorithm versus age.

Using 250 µm as the minimum diameter of a pore, the pore density appears to be very low in comparison with literature values (about 60 pores per cm^2 vs more than 300 pilosebaceous follicles per cm^2 in the literature[5,21,22]). Indeed, the algorithm only takes visible pores into account, but literature often describes sebaceous follicles that are much smaller than pores that the eye can detect. This is confirmed by the lower number of spots detected on sebum-absorbent tape (about 150–250 per cm^2 according to literature[21,23]).

Data versus age does not show any correlation irrespective of the method used, either visual grading by experts or automated calculation (Figure 8). With a larger number of participants on a larger age scale, our results confirm those from Roh et al[3] regarding the link between pore size and age. According to Piérard-Franchimont et al,[24]

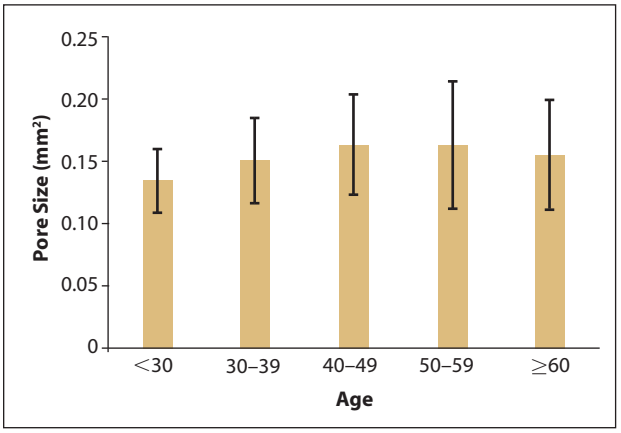


Figure 9. Pore size measured with the algorithm versus age groups.

the influence of age on pore enlargement would be moderated by hormonal impact. Figure 8 shows that linear regression is not significant, but Figure 9 suggests that the linear model may not be the better one to fit the data. There would be a peak at approximately age 50 years and a decrease beyond that. Women older than 50 years would be subject to a decrease in pore opening concomitantly with a decrease in sebum production following hormonal depletion. Menopause and hormone replacement therapy have not been taken into account in this study, therefore we cannot give more support to the origin of this decrease.

CONCLUSION

The main concern for women is the visibility of pores; hence the first method used to assess this parameter was a clinical evaluation by direct observation of the surface of the face. Visual assessment, however, is subject to human error.

The Dermascore associated with a specific pore chart has provided a novel improvement in the reliability of evaluation.[15] The use of a scale enables standardized references to be defined, which increases the robustness, reproducibility, and sensitivity of the grading process.

Photographs taken during the trial allow the quality of evaluation to be improved further. Photographs can be evaluated using magnification on a screen and then graded by an expert panel as described in this study.

The aim of the present study was to validate the final step in improvement, consisting in using a software system for measuring pore size. This step enables objective evaluation of the parameter because no human involvement is required. The image analysis process is automated and is only influenced by the quality of the photographs (eg, focus or contrast).

Thus, the new image analysis quantification software is a reliable tool for the assessment of parameters of facial pore characterization (number and size) because it provides data in accordance with human perception of pore visibility. Moreover, this last point also confirms that the reference chart associated with the observation device is a valuable and easy-to-use tool for direct clinical evaluation.

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