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Assessment technique for acne treatments based on statistical parameters of skin thermal images

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Abstract. Acne vulgaris as an inflammatory disease, with an excessive production of subdermal fat, modifies the dynamics of the bloodstream, and consequently temperature, on the affected skin zone. A high percentage of this heat interchange is manifested as electromagnetic radiation with far-infrared wavelengths, which can be captured through a thermal imaging camera. A technique based on thermal image analysis for efficiency assessment in acne vulgaris is described. The procedure is based on computing statistical parameters of thermal images captured from the affected skin zone being attended by an acne treatment. The proposed technique was used to determine the skin thermal behavior according to acne severity levels in different acne treatment stages. Infrared images of acne skin zones on eight patients, diagnosed with acne vulgaris and attended by one specific acne treatment, were weekly registered during 11 weeks. The infrared images were captured until no more improvement in affected zones was detected. The obtained results suggest a direct relationship between the used statistical parameters, particularly first- and second-order statistics, and the acne vulgaris severity level on the affected zones. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.JBO.19.4.046019](https://doi.org/10.1117/1.JBO.19.4.046019)]

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1 Introduction

Acne vulgaris is a skin disease affecting more than 80% of the worldwide population with ages between 15 and 44 years old.^{1,2} Although acne vulgaris is frequently seen as a noncritical dermatological condition, it is highly related with social, psychological, and emotional problems in the patient, such as the ones caused by critical diseases, like asthma, epilepsy, diabetes, and arthritis. The highest effects on the patient are presented when the acne is physically located on the face, where it is difficult to hide. One of the effects is the underdevelopment of social skills in the patient, and consequently interpersonal relationships.^{3,4} Fortunately, there are several acne treatments available to notably improve the quality of life for patients having this skin disease.

Acne vulgaris as an inflammatory disease, with an excessive production of subdermal fat, modifies the dynamics of the bloodstream, and consequently temperature, on the affected skin zone. Factors responsible for heat variations of the skin might be environmental, such as temperature, humidity, and speed of wind, or might be physiological, such as internal body temperature, heat conduction through the tissue, or bloodstream.⁵ The human body surface, as part of a thermal regulation process, requires different heat interchange levels with the environment. A high percentage of this heat interchange is as electromagnetic radiation within the far-infrared range, which can be measured through a thermal imaging camera. Skin damage zones can be located by the heat variations sensed through thermal imaging, where the hot areas are correlated to skin zones having higher bloodstream. Basically, the thermogram is a skin temperature map, where the increase in the

bloodstream can be identified, indicating skin irritation or lesion in this way.⁶⁻⁹

The use of noninvasive techniques in diagnosing the level of skin acne is a real challenge; some skin lesions are difficult to identify using traditional photography because of image saturation caused by artificial light, such as flash light. Other techniques, having better results, suggest the use of fluorescent photography for detecting Propionibacterium acne suppression due to antibacterial agents, like benzoyl peroxide.^{10,11} Several research works related to diagnosing acne severity level have been reported, most of them are based on quantifying parameters, such as types, number, distribution, and density of lesions. Although such diagnosing methods are relatively simple, dermatologists' experience and subjectivity are strongly needed.¹²⁻¹⁵

The acne severity level (grading) is frequently determined subjectively. Different acne grades may be given to the same area of acne by different dermatologists. However, all reported techniques for the evaluation of acne severity level are based on the number and appearance of acne skin lesions, for which severity level is classified into scales. Nowadays, new alternative evaluation techniques for acne severity level are emerging, such as polarized light photography, video microscopy, and multispectral image analysis, where a direct relationship between skin disease conditions and the spectral characteristics of reflected light are established.¹⁶ Image digital processing methods are frequently used by such new techniques for tasks such as segmentation of skin lesion images using binarization and special filtering algorithms, lesion edges detection, image contrast enhancement, and lesion counting and classification through inference algorithms, such as the recently reported color segmentation, K-means clustering, Bayes classifier, maximum entropy classifier, and linear discrimination functions.¹⁷⁻¹⁹

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A technique based on thermal images and statistical parameters for the assessment of acne vulgaris is proposed in this article. The research is focused on finding out a relationship, using first- and second-order statistics, between the acne vulgaris severity level and the average temperature on the affected zones. The technique was used to determine the skin thermal behavior according to its acne severity levels in different stages of an acne treatment. Infrared images of eight patients diagnosed with acne vulgaris were captured weekly for 11 weeks, applying one specific acne treatment until no more improvement in the affected zone was detected.

2 Materials and Methods

The study was done on seven patients having acne papulopustulosa and one having acne comedones. The patients' data are shown in Table 1, where gender, age, and acne severity level before, after, as well as in the middle of the study are presented. The acne severity level for each patient was diagnosed by dermatologists using the classification proposed by Hayashi et al.²⁰ Same acne treatment was applied to each patient, consisting a weekly applying of benzoyl peroxide gel, with a concentration of 1%, on affected skin zone for 5 min; the procedure was complemented by applying a water steam flow containing an ozone gas concentration of 0.1%. As it is well known that both substances have antimicrobial and antibacterial properties, being the reason why they are frequently used to treat acne.²¹⁻²³

Each acne treatment session consisted of four stages: (1) skin chemistry exfoliation using alpha-hidroxy acids, (2) saponification of fat glandules and activity excess using biosulfur and salicylic acid, (3) bacterial population control through benzoyl peroxide and ozone, and (4) skin inflammation control using calendula, chamomile, and aloe vera.

All participants were aware about the study objective and informed that thermogram capture does not imply any risk to health. In order to determine the image capture conditions, several tests were made previously to the capture section. The RGB acne image of one patient is shown in Fig. 1(a), and the corresponding temperature map obtained through the thermogram capture is presented in Fig. 1(b). From these two images, it is possible to see that the acne zone location agrees with the



(a)



(b)

Fig. 1 Patient's image samples: (a) RGB and (b) thermograph.

Table 1 Study patients' data, acne severity levels according to Hayashi et al.²⁰

Patient number	Gender	Age (years)	Acne severity level (before treatment)	Acne severity level (middle of treatment)	Acne severity level (after treatment)
1	Female	27	Severe	Moderate	Mild
2	Male	15	Severe	Moderate	Mild
3	Male	18	Severe	Severe	Severe
4	Female	23	Severe	Moderate	Mild
5	Female	22	Moderate	Moderate	Moderate
6	Male	14	Severe	Severe	Severe
7	Male	23	Severe	Moderate	Mild
8	Male	18	Severe	Moderate	Mild

thermal skin map, where high-contrasted areas correspond to skin zones affected by acne. Thermal changes on skin zones due to the applied acne treatment might be altered by pathological causes. In order to reduce such causes, patients with some infection process or some pathology such as diabetes or heart disease, were not included in the study sample. Besides, pregnant patients or patients in menstrual period were also excluded.

Before the application of the acne treatment on affected skin, three steps were followed for capturing the thermographic images. (1) Each patient was relaxed for 30 min in a room with a controlled temperature of 25°C (±1°C). (2) In order to obtain an image with improved contrast level, an uniform and thin layer of sunscreen, based on titanium dioxide crystals, was applied on each patient's skin²⁴ using a spatula, achieving thermal equilibrium between the skin and the sunscreen can be achieved. (3) The skin temperature map was obtained through a thermographic camera Flir E45,²⁵ which has a spectral range from 7.5 to 13 μm and a thermal resolution of 0.2°C, based on a semiconductor AlGainP diode laser with 1 mW/635 nm. The camera was placed at a distance of 60 cm from the skin and calibrated to capture a temperature range between 22°C and 35°C with an emissivity coefficient of 0.98.

The above procedure was followed for 11 weeks for each patient, always before the acne treatment session, as suggested by dermatologists to reduce the acne severity level. Some of the patients showed a significant acne level reduction in just 7 weeks. They had a fast response to the applied treatment and for them only seven thermograms were captured. A treatment

period of 11 weeks was needed for rest of the patients; hence capture and analysis of 11 thermographic images were done. The captured thermograms of skin affected by acne were analyzed using first- and second-order statistics. The analyzed image pixels were chosen as those on an irregular polygon zone covering the affected skin. The same polygon zone was used for all thermographic images of the same patient. Different polygon zones were applied for different patients, but all having an average zone area of 480 mm².

2.1 First-Order Statistics

The first-order statistics were computed through the media (*m*) and standard deviation (*σ*) of the pixel values on the polygon zone, given respectively as

$$m = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} f(i, j), \tag{1}$$

and

$$\sigma = \sqrt{\frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} [f(i, j) - m]^2}, \tag{2}$$

where *i* = 0, 1, 2, ..., *M* - 1, and *j* = 0, 1, 2, ..., *N* - 1 are the coordinates of each thermogram pixel, *M* and *N* represent the size of analyzed image (*M* = 320 and *N* = 240).

2.2 Second-Order Statistics

The second-order statistics were computed through the co-occurrence matrix *G*, of which element *g_{ij}* represents the number of times that a pixels pair having intensity levels *z_i* and *z_j* are present on the image intensities map in a position indicated by the operator *Q*, where 1 ≤ *i, j* ≤ *L* with *L* as the number of possible intensities levels. Hence, the concurrence probability of each pixels pair is computed as

$$p_{i,j} = \frac{g_{i,j}}{n}, \tag{3}$$

where *n* is the total number of pixels pairs satisfying operator *Q*.

Among the analyzed second-order statistical indices, the homogeneity parameter (*H*) was the one that best represented the acne severity level changes on studied patients. Such index is obtained from the probability values *p_{i,j}* as²⁶

$$H = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \frac{p_{i,j}}{(1 + |i - j|)}. \tag{4}$$

3 Results

A notable reduction in the acne severity level on five of the eight patients was achieved by the applied treatment. This reduction could be confirmed through their average temperature and homogeneity values computed from the co-occurrence matrix. The average initial and final temperatures, as well as the temperature difference for each patient, are presented in Table 2. A decrease of the average temperature on the acne zone for patients 1, 2, 4, 6, 7, and 8 was detected. A temperature difference smaller than 2 deg was presented only on patient 6. Higher

Table 2 Average values of initial (*T_i*), final (*T_f*), and difference (*ΔT*) temperature on acne zone of patients.

Patient	<i>T_i</i> (°C)	<i>T_f</i> (°C)	<i>ΔT</i> = <i>T_i</i> - <i>T_f</i> (°C)
1	32.97	28.43	4.49
2	31.47	29.25	2.22
3	31.71	31.74	-0.03
4	32.61	28.88	4.33
5	29.28	30.82	-1.54
6	32.28	30.37	1.91
7	32.44	28.93	3.51
8	32.35	31.12	2.23

final average temperature values were detected on patients 3 and 5, which agreed with the increase of acne severity levels on such patients. According to *t*-test, for small samples applied on initial and final temperature values of Table 2, the null hypothesis (*H₀*: The initial and final temperatures median values are equal) was rejected (*α* = 0.005, *p*-value = 0.0028, *T*-test = 3.268, *Tα* = 2.921) and the alternative hypothesis (*H_a*: Initial temperature media value is higher than final temperature media value) was accepted.

The thermal behaviors of the average temperature values throughout the treatment for patients 1, 2, 4, 7, and 8 are depicted in Fig. 2, where each graph point represents the average temperature value on the acne zone of each patient.

As it is shown in Fig. 2, only seven thermographic images for patients 4 and 7 were captured and analyzed, this is because the acne was completely disappeared in the seventh week for both patients. Ten and eleven thermographic images were captured for the rest of patients. According to Fig. 2, a direct relationship between acne severity level and skin average temperature was resulted. The lower acne severity level achieved by the treatment is the greater reduction of the average skin temperature. The weekly average temperature values of the skin zone affected by acne for patients with an improvement of acne severity level are depicted in Table 3.

As an illustrative example, two thermograms of patient 1 are pseudocolored as shown in Fig. 3. The thermogram at the first session, before the acne treatment, is presented in Fig. 3(a). The thermogram obtained at the tenth week, after the acne treatment and once a significant reduction of acne severity level was diagnosed by dermatologists, is shown in Fig. 3(b). From these two images, a notable change of the skin temperature map is detected. A lower temperature value was measured on acne skin zones at the end of the treatment, Fig. 3(b), which agrees with the achieved acne severity level reduction. The temperature reduction is also presented on skin area around the acne skin zones. The reason for this global skin temperature decrease is that a reduction of skin inflammation was resulted by the applied acne treatment. In this way, a lower face bloodstream as well a production drop of fat affected by *Propionibacterium acnes* bacteria were achieved. According to Nilsson,⁶ there is a linear relationship between skin temperature and bloodstream.

Thermal behavior of average skin temperatures for patients 3, 5, and 6 (see Table 1) is shown in Fig. 4. The captured skin

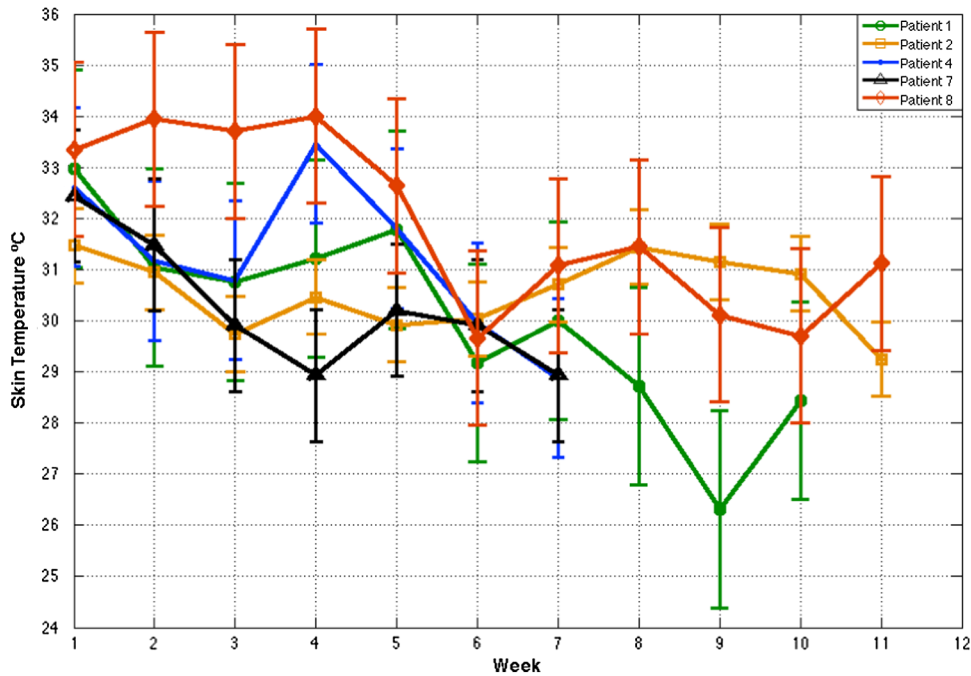


Fig. 2 Thermal behaviors of patients having an improvement with applied treatment.

Table 3 Weekly average temperature values for patients with acne level improvement.

Patient	Week										
	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)	7 (°C)	8 (°C)	9 (°C)	10 (°C)	11 (°C)
1	32.9	31.0	30.7	31.2	31.7	29.1	30.0	28.7	26.3	28.4	—
2	31.4	30.9	29.7	30.4	29.9	30.0	30.7	31.4	31.1	30.9	29.2
4	32.6	31.1	30.7	33.4	31.8	29.9	28.8	—	—	—	—
7	32.4	31.4	29.9	28.9	30.2	29.9	28.9	—	—	—	—
8	33.3	33.9	33.7	34.0	32.6	29.6	31.0	31.4	30.1	29.7	31.1

temperatures for patients 3 and 5 at the end of treatment were higher than the initial ones. According to our hypothesis, these temperature results mean an increase of the acne severity level at the end of the treatment, which was confirmed by the dermatology results. In the case of patient 6, the acne severity level was slowly reduced until sixth week, but such achieved level was increased in the following four sessions resulting in a higher temperature value at the tenth week.

Thermograms for patient 5 are pseudocolored as shown in Fig. 5. The thermogram at the first session, before that acne treatment, is presented in Fig. 5(a) and the one at eighth week, after the last treatment session, in Fig. 5(b). As can be seen, there is no significant difference in the average temperature of the acne affected zones in both session images.

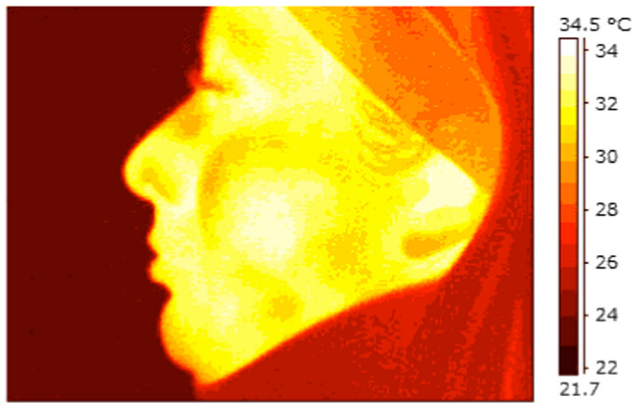
The obtained results using first-order statistics were confirmed with the homogeneity parameter value, computed with co-occurrence matrix [see Eq. (4)]. The computed homogeneity values for patients 1, 2, 4, 7, and 8, according to first-order statistics analysis resulted with acne severity improvement, are shown in Fig. 6. As can be seen, a reduction

trend of thermogram homogeneity values was obtained. The final homogeneity value is smaller than the initial one for all the cases.

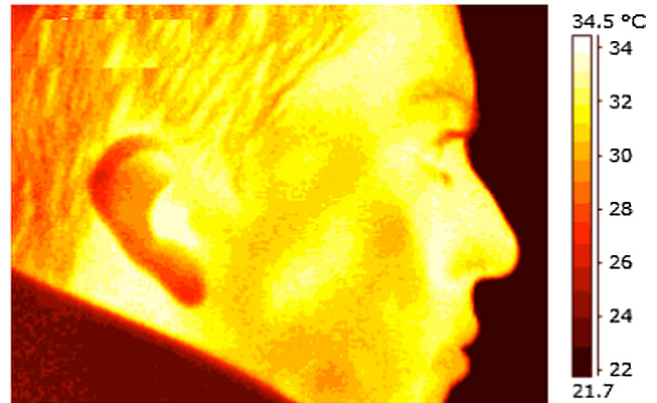
Regarding to the second-order statistical analysis of patients without improvement in acne severity level, the behaviors of thermogram homogeneity values were almost constant along the treatment, as can be seen in Fig. 7. For the three cases, the final homogeneity value was greater than the initial one.

4 Discussion

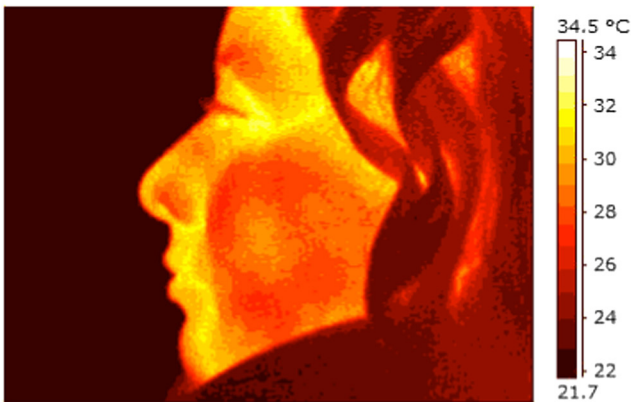
Although several diagnosing techniques have been reported for determining severity level in inflammatory and noninflammatory acnes,^{10,12,17} visual and touching inspections are the most frequently used techniques by dermatologists when diagnosing severity level on the affected skin zone. Huamyun and Malik²⁷ proved that it is possible to use multispectral and thermal images for classifying acne severity levels; their work is based on correlation computing of multispectral images. However, such classification still requires a visual analysis of resulting image and image histogram.



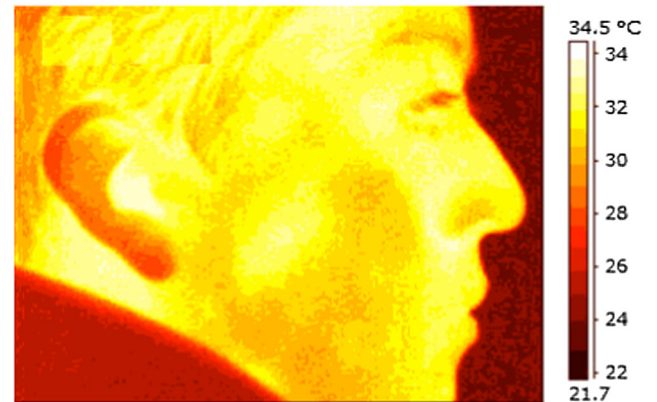
(a)



(a)



(b)



(b)

Fig. 3 Thermograms of patient 1: (a) before and (b) after acne treatment.

Fig. 5 Thermograms of patient 5: (a) before and (b) after acne treatment.

As already reported results show, thermography is a useful tool in determining the acne severity level on skin. This is because quantitative information can be obtained from the thermogram, allowing an objective evaluation of the acne severity level. Although emissivity coefficient of skin may be altered by the applied sunscreen layer, this emissivity change was not taken into account in the study analysis because a

small thermal effect is obtained by the thin and applied sunscreen layer, achieving a thermal equilibrium like in the topical-treated skin in Ref. 28. This is based on the small change of emissivity coefficient value of the skin covered by the sunscreen layer. The computed value of such emissivity coefficient was 0.92, which is not significantly larger than the emissivity

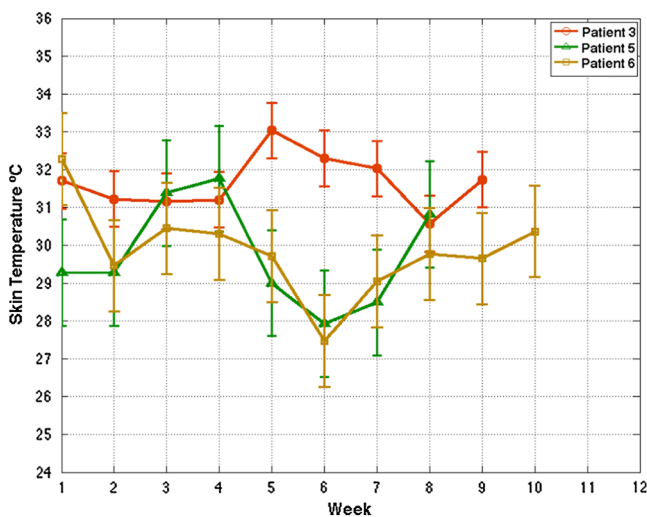


Fig. 4 Average skin temperature values for patients with no acne severity level improvement.

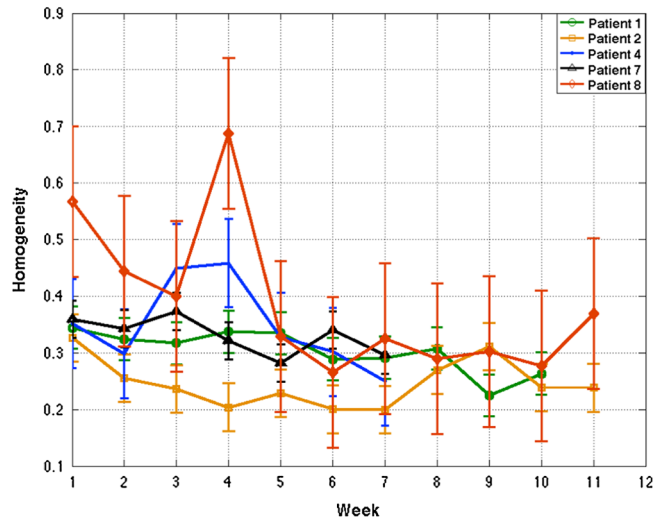


Fig. 6 Thermogram homogeneity values for patients with acne severity improvement.

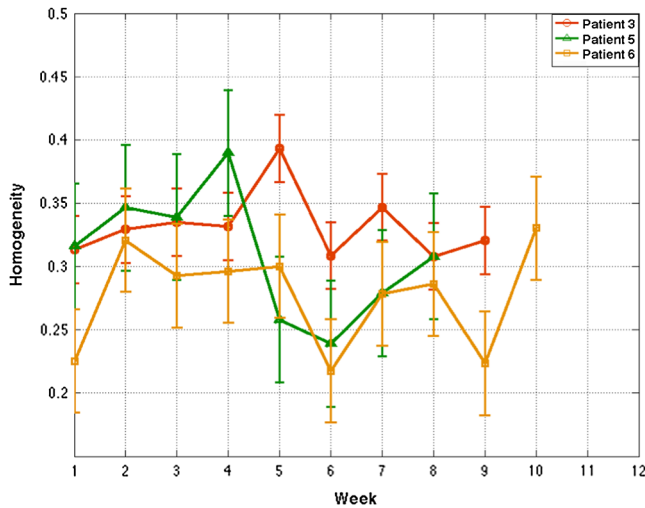


Fig. 7 Thermogram homogeneity values for patients with no acne severity improvement.

coefficient value of human skin covered without the sunscreen layer (0.98). The reported results in this article suggest statistical parameters of media and homogeneity, obtained from the thermal maps of acne skin zones, as a helpful tool for determining if acne severity level is reduced or not throughout the use of one specific acne treatment. Such statistical parameters might be mainly helpful for efficiency assessment in early stages of acne treatments, when neither visual nor touching results are available, approximately at fourth or sixth week.

Among all second-order statistical indices computed from captured thermographic skin images, the homogeneity parameter was the one with the best results in quantitatively estimating the acne severity level along the applied acne treatment. The high-homogeneity values were obtained for patients with high-acne severity levels, and the smallest values for patients with low and moderate acne severity levels. From obtained results, an explanation to this homogeneity value behavior is that image pixels values are locally homogeneous on skin zone affected by acne, as long as acne severity level is reduced the pixels values are scattered, reducing in this way their homogeneity as a consequence of the infrared radiation dispersion reflected on the human skin.

The use of the first-order statistics, based on the media parameter computing from captured images, allowed the global evaluation of temperature variations on skin affected by acne. On the other hand, local temperature variations were possible to be detected by using the second-order statistics and the homogeneity parameter value. Therefore, it is possible to asseverate that the average temperature value on affected skin zone is decreased, the temperature gradient value of local skin zones is incremented, and the skin behaves as a healthy one with an infrared emission similar to a normal distribution.²⁹

5 Conclusions

Statistical analysis results of thermal images captured from patients' skin having acne vulgaris along a specific treatment are presented in this article. The project goal was focused to find out a possible relationship between the acne severity level and the obtained statistical data along the treatment stages.

The computing of several statistical parameters was done for thermal images captured from eight patients in a period of time

of 7 and 11 weeks. According to the obtained results, the first- and second-order statistical parameters media and homogeneity, respectively, showed a direct relationship to the acne severity level. In this way, such statistical parameters may be used as a quantitative assessment tool for acne treatments efficiency mainly in early stages, when neither visual nor touching results are available, approximately at the fourth or sixth week. The proposed method might be extended as future work to applications on treatment assessment of other skin diseases like psoriasis, vitiligo, or even skin burns.

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