

Review

Acne analysis, grading and computational assessment methods: an overview

Roshaslinie Ramli¹, Aamir Saeed Malik¹, Ahmad Fadzil Mohamad Hani¹ and Adawiyah Jamil²

¹Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, Perak, Malaysia and ²Department of Dermatology, Hospital Kuala Lumpur, Kuala Lumpur, Malaysia

Introduction: This paper presents a comprehensive review of acne grading and measurement. Acne is a chronic disorder of the pilosebaceous units, with excess sebum production, follicular epidermal hyperproliferation, inflammation and *Propionibacterium acnes* activity. Most patients are affected with acne vulgaris, which is the prevalent type of acne. Acne vulgaris consists of comedones (whitehead and blackhead), papules, pustules, nodules and cysts.

Objectives: To review and identify the issues for acne vulgaris grading and computational assessment methods. To determine the future direction for addressing the identified issues.

Methods: There are two main methods of assessment for acne severity grading, namely, lesion counting and comparison of patient with a photographic standard. For the computational assessment method, the emphasis is on computational imaging techniques.

Results: Current acne grading methods are very time consuming and tedious. Generally, they rely on approximation for counting lesions and hence the assessment is quite subjective, with both inter and intra-observer variability. It is important to accurately assess acne grade to evaluate its severity as this influences treatment selection and assessment of response to therapy. This will further help in better disease management and more efficacious treatment.

Conclusion: Semi-automated or automated methods based on computational imaging techniques should be devised for acne grade assessment.

Key words: acne vulgaris – acne types – acne lesions – acne grading – acne treatment – acne therapy – acne imaging methods

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CLINICALLY, ACNE occurs when hair follicles, which are often called skin pores inside the human skin, become blocked. Small oil gland called sebaceous glands, which are located around hair follicles, produce an oily substance called sebum (Fig. 1). The sebum, which normally drains to the surface through the hair follicle, is trapped within the skin pore when the hair follicles become blocked. From this, bacteria known as *Propionibacterium acnes* (1) eventually attack the sebum, thereby producing skin inflammation and acne.

Acne is a common skin disease that affects 85% of adolescents (2) at some time during their lives. Acne affects the areas of skin with the densest population of sebaceous follicles, which is face, the upper part of the chest and the back (1). The prevalence and severity of acne on the face, chest and back was shown to be 92%, 45% and 61%, respectively (3). Every year, the total cost is estimated to exceed US\$1 billion for acne treat-

ment (4). In Malaysia, about RM 250 (US\$ 80) are spent for the medication of one patient in a year.

Types of acne

Generally, there are various types of acne such as acne conglobata, acne excoriee, acne rosacea, acne cosmetica, pomade acne, acne fulminans, acne keloidalis nuchae, acne chloracne, acne mechanica and acne medicamentosa (1). But acne vulgaris is a common acne prevalent in 99% of the acne cases and it is differentiated mainly based on lesion type as well as the underlying cause, e.g., acne cosmetica is caused by the use of cosmetics, mechanica in people who tend to lean their face on the hands or pressure areas from helmets, etc., medicamentosa due to topical medicine applied on the skin and pomade acne due to the use of talcum powder. The lesions seen in acne vulgaris are comedones, papules, pustules, nodules, cysts and, in some cases, scarring

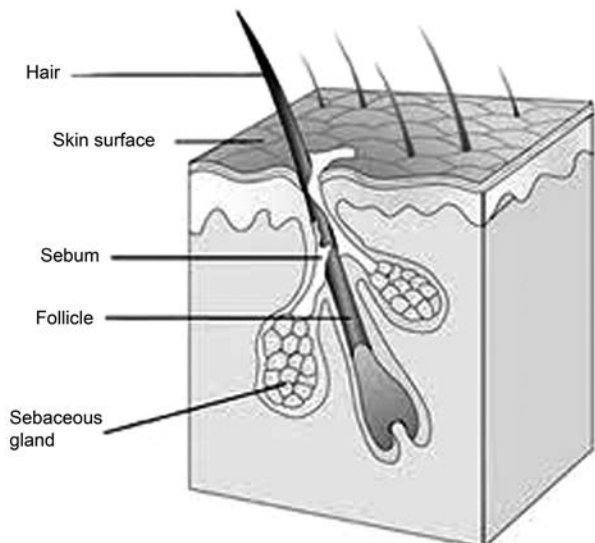


Fig. 1. Schematic view of the hair follicle and sebaceous gland.

(5). Therefore, in this paper, we focus only on acne vulgaris.

Acne Lesions

Acne vulgaris is characterized by non-inflammatory, open and closed comedones and by inflammatory papules, pustules and nodules. A closed comedo is a whitehead and an open comedo is a blackhead. A whitehead is an acne lesion that forms when oil and skin cells block the opening of hair follicle (Fig. 2a). This usually appears on the skin as small, whitish bumps and under the surface of the skin. The chronic whitehead is called milia and it is a tiny white bump that occurs when normally sloughed skin cells become trapped in small pockets on the surface of the skin. They are common across the nose and upper cheeks (Fig. 2b). A blackhead is a non-inflammatory acne lesion that is filled with excess oil and dead skin cells. Black-head is called an open comedo because the surface of the skin remains open with a dark appearance such as black and brown color (Fig. 2c).

Swelling, heat, redness and pain occur as a reaction of tissue to disease and these symptoms are classified as inflammation. It is caused by chemical irritation from sebum mechanism for instance fatty free acids. Papules become visible on the skin as a small and firm pink bump (Fig. 2d). Frequently, papules are considered an intermediary step between non-inflammatory and inflammatory, but obviously, papules are inflammatory lesions. Pustules are full of visible pus, which emerges red at the base with a yellowish or

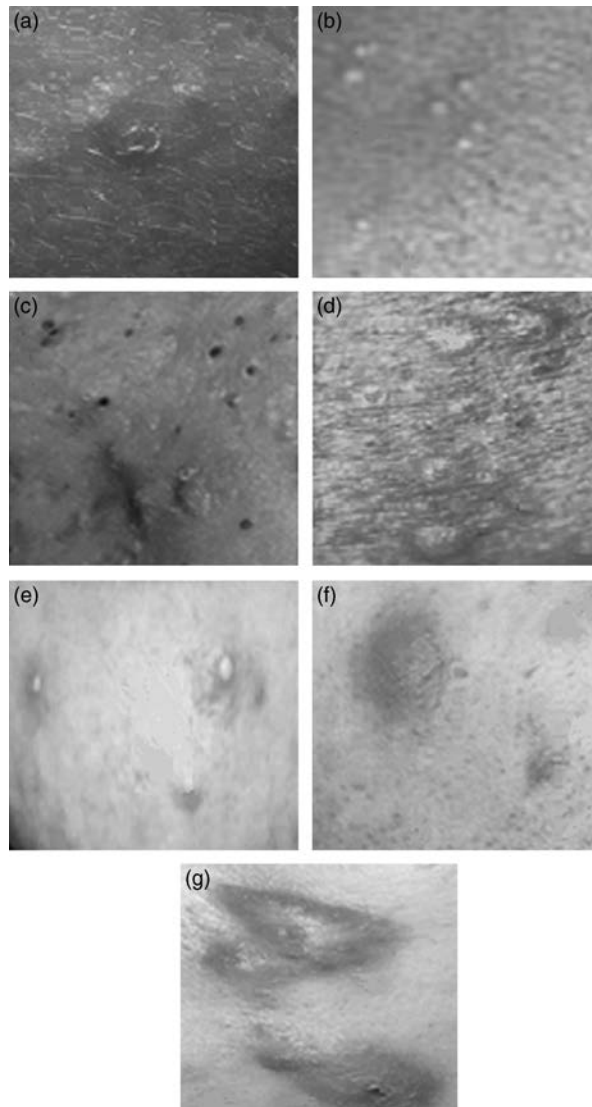


Fig.2. Acne lesions. (a) Whitehead (closed comedones), (b) milia, (c) blackhead (open comedones), (d) papules, (e) pustules (f) nodules (g) cysts.

a whitish center with small round lesions that are inflamed (Fig. 2e). Pustules do not contain a large amount of bacteria. Papules and pustules comprise about 90% of the total cases.

A nodule is similar to a papule, but is greater than either 5 or 10 mm in both width and depth, and most frequently centered in the skin (Fig. 2f). Cysts are large pus-filled lesions that are usually present deep within the skin. The cysts are very painful lesions, as they are inflammatory (Fig. 2g). Cysts form as a result of the contents of a comedo spilling over the surrounding skin and due to the response of the local immune system in producing pus. The cysts often leave deep scars. Generally, patients have a combination of non-inflammatory and inflammatory acne. Table 1 provides the details of all the above-mentioned lesions.

TABLE 1. Details of acne lesions

Acne lesion	Size	Color	Pus	Effect	Comments
Whitehead	Tiny	Whitish	No	No pain, non-inflammatory	Chronic whitehead is called milia
Blackhead	Tiny	Black or brown	No	No pain, non-inflammatory	Not dirt but black due to excess oil and dead cells
Papule	<5 mm in diameter	Pink	No	Warm and painful, inflammatory	Very common
Pustule	<5 mm in diameter	Red at the base with a yellowish or a whitish center	Yes	Warm and painful, inflammatory	Very common
Nodule	5–10 mm in diameter	Pink and red	No	Warm and painful, inflammatory	Nodule is similar to papule but is less common
Cysts	More than 5 mm	Red	No but has liquid inside	Warm and painful, inflammatory	Least common

Causes of Acne

There are various causes for acne including genetic, hormonal, sebaceous activity, bacteria, climate, chemical and psychological. Generally, acne is due to more than one factor but the dominant factor is genetics. If both parents had acne, three out of four children will have acne. If one parent had acne, then one out of four children will have acne. However, similar to other genetic conditions, not every family will have the same pattern, with acne vulgaris sometimes skipping generations.

Hormonal activity such as menstrual cycles and puberty is one of the causes for acne. During puberty, the increase in male sex hormones called androgens causes the sebaceous gland, which is located around a hair follicle, to grow larger and produce more sebum. Sebaceous glands are affected when their activity become hyperactive compared with normal activity. *P. acnes*, will attack the sebum that is trapped under the skin surface when the hair follicles become blocked.

In a hot climate, sebaceous glands produce more oily substance called sebum, which may cause acne. Chemical factors like facial wash and exposure to certain chemical compounds, particularly linked to toxic exposure to dioxin, may also cause acne. Stress is a psychological factor that makes sebaceous gland hyperactive and may cause acne.

Organization of the Paper

This paper is divided into two distinct but inter-related sections. The first section summarizes the various acne grading systems and provides the relevant grading tables. The second section discusses in detail the computational methods that have been proposed for diagnosing the acne

grade, which may lead to better assessment of the acne grade.

Acne Assessment

To date, there are more than 25 different grading systems for the assessment of acne severity that have been published in literature. Lehmann et al. (6) have surveyed at least 25 scales for assessing the global severity of acne. However, the existence of so many grading systems indicates a lack of consensus on this issue and hence no grading system is considered to be a global standard. All the grading systems place different emphasis on counting acne lesions as well as for comparison of the patients with a photographic standard. Generally, a grading system aims to achieve simplicity, accuracy and a quick assessment.

For the acne lesion-counting method, the numbers of open and closed comedones, papules, pustules and nodules are counted. For the photographic method, the patient photos are compared with the photographic standard. The first person who used a scoring system for acne vulgaris was Carmen Thomas of Philadelphia. She used lesion counting in her office notes, starting in the 1930s (7). However, the first grading system was introduced by Pillsbury et al. (8). This grading is based on an overall estimate of the type of lesion, the number of lesions and the predominant lesion.

Table 2 provides the grading introduced in (8). Patients are classified as Grade 1 if they have comedones that are blackheads and blackheads joining with very rare small cysts in their face. Grade 2 is for patients who have comedones and very rare pustules and small cysts restricted to their face. Patients who have many comedones with small or large papules and pustules spread out but still restricted to the face are labeled as Grade 3. Grade 4 is for patients who have many

TABLE 2. First grading system (8)

Grade	Description
Grade 1	Comedones and occasional small cysts confined to the face
Grade 2	Comedones with occasional pustules and small cysts confined to the face
Grade 3	Many comedones and small and large inflammatory papules and pustules, more extensive but confined to the face
Grade 4	Many comedones and deep lesions tending to coalesce and canalize, and involving the face and the upper aspects of the trunk

TABLE 3. Grading system by James and Tisserand

Grade	Description
Grade 1	Simple non-inflammatory acne comedones and a few papules
Grade 2	Comedones, pustules and a few pustules
Grade 3	Larger inflammatory papules, pustules and a few cysts; a more severe form involving the face, neck and upper portions of the trunk
Grade 4	More severe, with cysts becoming confluent

comedones combined with deep lesions on the face and the upper trunk.

In 1958, James and Tisserand presented an alternative grading scheme in their review of acne therapy (9). Table 3 provides the grading system presented by them. Grade 1 is selected if there are blackheads, whiteheads and a few papules dominant at the affected skin area as described in Table 3. Then, Grade 2 is identified if there are blackheads, whiteheads, papules and a few pustules prevalent on patients' skin. Several papules, pustules and a few cysts at the face, neck and upper portions of the trunk are defined as Grade 3. If the condition becomes more severe, with cysts becoming worse, it is categorized as Grade 4.

In 1966, Witkowski and Simons initiated lesion counts for assessing the severity of acne vulgaris (9). The numbers of closed comedones, open comedones, papules, pustules and nodules were recorded. Papules and pustules were divided into small and large lesions. Nodules or cysts were termed as abscesses. The underlying concept behind their method was that lesions were counted on one side of the face as a time-saving measure. Then, once they were recognized, the number of lesions on the left side was assumed to be nearly equal to those on the right side. This concept was extended with the acne flow form and the acne questionnaire (9).

TABLE 4. The Frank numerical grading table

Types of lesion	Numbers of lesion
Comedones	10
Papules	7
Pustules	5
Cicat	2

TABLE 5. Classification of acne severity on lesion counting of comedonal and papulopustular per half face

Grade	Comedonal	Papulopustular
1	Fewer than 10 comedones	Fewer than 10 inflammatory lesions
2	Between 10 and 25 comedones	Between 10 and 20 inflammatory lesions
3	Between 25 and 50 comedones	Between 20 and 30 inflammatory lesions
4	More than 50 comedones	More than 30 inflammatory lesions

The acne flow is for maintaining good records on acne patients and each dermatologist can easily produce his own form. This form provides an accurate method of entering and retrieving information and evaluating progress. In order to determine the reasons for acne flares or failures in response, a printed questionnaire can be used. This method is more accepted by patients and improves the efficiency of the result.

In 1971, Frank created a numerical grading of each type of lesion on the face, chest and back (9). He proposed grading from either 0–4 based on severity and provided a table for recording the results (Table 4). The number of lesions based on types of lesion was counted. Then, he used the James and Tisserand method of grading to provide grading, which is shown in Table 3.

In 1975, Plewig and Kligman, in their textbook, introduced numerical grading (9). They calculated separately the comedonal acne and papulopustular acne and the overall severity were graded with Grade 1 to Grade 4 depending on the number of lesions (Table 5). The term comedonal acne is used to describe a form of non-inflammatory acne that consists of whiteheads and blackheads. The papulopustular acne is inflammatory acne that contains both papules and pustules.

Grade 1 for comedonal acne means that the patient has fewer than 10 whiteheads and blackheads per half face, while Grade 1 for papulopustular shows that a patient has fewer than 10 papules and pustules per half face. For Grade 2

TABLE 6. Scale of acne severity based on percentage of reduction

Scale	Percentage of reduction	Level
4	100% reduction	Excellent
3	75–99% reduction	Good
2	50–74% reduction	Moderate
1	1–49% reduction	Insufficient
0		Unchanged
–1		Worse

TABLE 7. Severity index based on types of lesions

Severity index	Types of lesion
0.5	Comedones
1.0	Papules
2.0	Pustules
3.0	Infiltrates
4.0	Cysts

comedonal acne, a patient has between 10 and 25 whiteheads and blackheads per half face, while Grade 2 for papulopustular means that the patient has between 10 and 20 papules and pustules per half face. Grade 3 for comedonal acne indicates that the patient has between 25 and 50 whiteheads and blackheads per half face, and Grade 3 for papulopustular shows that patient has between 20 and 30 papules and pustules per half face. Grade 4 for comedonal acne means that the patient has more than 50 whiteheads and blackheads per half face, while Grade 4 for papulopustular indicates that the patient has more than 30 papules and pustules per half face. This grading is shown in Table 5.

In 1977, Christiansen and colleagues counted the total number of comedones, papules and pustules on the face instead of counting on half face (9). The area containing the most lesions was used as the test area. Lesions within a cardboard ring having an inner diameter of 5 cm were counted. For each visit, an overall evaluation was performed using a six-point scale, which is shown in Table 6.

Scale 4 indicates that the total number of patient’s lesions was 100% reduced compared with the last visit. It is classified as excellent. Then scale 3 indicates that the total number of patient’s lesions was reduced by 75–99% compared with the last visit. It is classified as good. Scale 2 shows that the total number of patient’s lesions was reduced by 50–74% compared with the last visit. It is classified as moderate, which means that the improvement due to the treatment

is more than 50% compared with the last visit. Scale 1 means that the total number of patient’s lesion was reduced by 1–49% compared with the last visit. It is classified as insufficient, which means that the patients’ recovery is <50%, thereby indicating that the treatment is not very effective. When patients do not have any reduction in terms of the total number of lesions since the last visit, they are in scale 0 and classified as unchanged. However, when the total number of lesions is increased compared with the last visit, they are in scale –1 and classified as worse. This indicates that the treatment is not effective and needs to be changed.

In 1977, Michaelson and colleagues counted the number of lesions on the face, chest and back (7). Each type of lesion was assigned a severity index (Table 7). The severity index is given based on the types of lesion. The severity index increases based on the most severe types of lesion. For example, the severity index of comedones that consist of blackheads is 0.5 compared with papules that have a severity index of 1.0. This is because papules are more severe than comedones. The same applies to pustules, infiltrates and cysts. Infiltrates are abnormal substances that accumulate gradually in cells such as nodules.

By multiplying the number of each type of lesion by its severity index and adding each product, these authors obtained a total score that represented the severity of the disease at each visit. For example, the patient has five comedones and eight papules. Thus, the number of each type of lesion is multiplied by its severity index, i.e., 0.5 comedones are multiplied with a 0.5 severity index and eight papules are multiplied with a 1.0 severity index. After multiplying, each product was added to obtain the total score. In the above example, the total score is 10.5. The total score will be calculated on every visit and compared with earlier scores to check whether the score is increasing or decreasing. If the total score is decreasing, it means that the number of lesion is reduced. But if the total score is increasing, it means that the number of lesions is increasing and hence the treatment should be changed.

In 1979, Cook et al. (10) devised a method wherein the overall severity of acne is evaluated on a 0–8 scale anchored to a photographic standard that illustrates grades 0, 2, 4, 6 and 8. They devised a system for photographing both sides of a patient’s face on a single exposure using a front-surface mirror. Then, independent examiners graded the

TABLE 8. Acne grading method by Cook et al. (10) using photographic standards

Grade	Description
0	Up to small scattered comedones and/or small papules are allowed
2	Very few pustules or three dozen papules and/or comedones; lesion are hardly visible from 2.5 m away
4	There are red lesions and inflammation to a significant degree; worth treating
6	Loaded with comedones, numerous pustules; lesions are easily recognized at 2.5 m
8	Conglobata, sinus or cystic type acne; covering most of the face

photographs at the end of the study according to Table 8. This method was supposed to be used in larger clinical trials, although the authors recommended lesion counting in pilot studies.

In their grading system, Grade 0 is assigned if patients just have comedones and small papules on their face while Grade 2 is assigned if few pustules or 36 papules and comedones are only just visible from 2.5 m away. Grade 4 is classified if there are red lesions such as papules, pustules and they are inflamed. Grade 6 indicates that a patient’s face easily shows comedones and pustules at 2.5 m, while Grade 8 is for cysts that cover most of the face.

In 1980, Wilson elaborated on this system, which Cook had initially devised in 1976 with Blaney and perfected at the 1978 American Academy of Dermatology meeting by inviting about 800 dermatologists to try his method (9).

In 1984, Burke and colleagues presented the Leeds technique, which described two scoring systems. The first is an overall assessment of acne severity for use in routine clinic and second a counting system for detailed work in therapeutic trials. A scale of 0 (no acne) to 10 (the most severe) was used for grading (9).

In 1985, Samuelson graded patients based on a set of nine reference photographs and determined the response to therapy in two steps. First, he asked the patients to compare their present appearance with the nine-grade scale. Second, he required the physician to record observations of comparison of the status with the nine-grade scale (9).

For example, in step 1, doctors asked their patients to compare their present appearance with a nine-grade scale. Then, let us assume that the patients said that their present appearance is the same as grade 5 in the reference photograph. Thus, in step 2, the physician recorded the observations of comparison of the status with the nine-

grade scale. Then, for the next appointment, they followed the same procedure. The degree of change is classified as excellent if the grade is decreased 3 or more. For example, on the first appointment, the patient is grade 5, and on the second appointment, the patient is grade 1. Thus, the degree of change for that patient is excellent. If the grade is decreased two grades, the degree of change is classified as good and moderate if the grade is reduced by only one. There is no degree of change if there was no change compared with the first appointment. The degree of change is worse if the grade is increased by 1 and more. At the completion of the study, independent examiners would also grade the photographs (Table 9).

In 1994, photography with fluorescence was used for the first time to assess the severity of comedonal acne (9). This method was explored by the Lucchina group (11) and they graded their observations on a fluorescence scale. They grade with 0 if patients do not have any acne in their face. Grade 1 is given for patients who have mild acne and Grade 2 for moderate acne. Grade 3 classified for extensive acne such as that shown in Table 10.

In 1996, Lucky et al. (12) assessed the reliability of acne lesions and they counted them. Then they recorded on a facial template and divided this into five facial segments, which are the right and the left forehead, the right and left cheek and the chin (Fig. 3).

Each lesion type such as open comedones, closed comedones, papules, pustules and no-

TABLE 9. The degree of change and description

The degree of change	Description
Excellent	There was a decrease of three or more grade numbers with reduced redness and tenderness
Good	There was a decrease of two grades with reduced redness and tenderness
Moderate	There was a decrease of one grade with reduced redness and tenderness
None	There was no change
Worse	There was an increase of one grade or more or an increase in redness or tenderness with the same grade

TABLE 10. The grade and scale

Grade	Scale
0	None
1	Mild
2	Moderate
3	Extensive

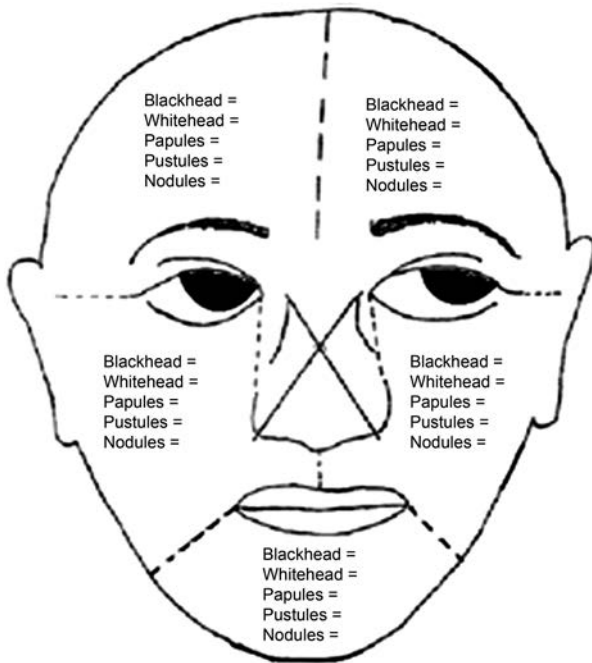


Fig. 3. Facial template (12).

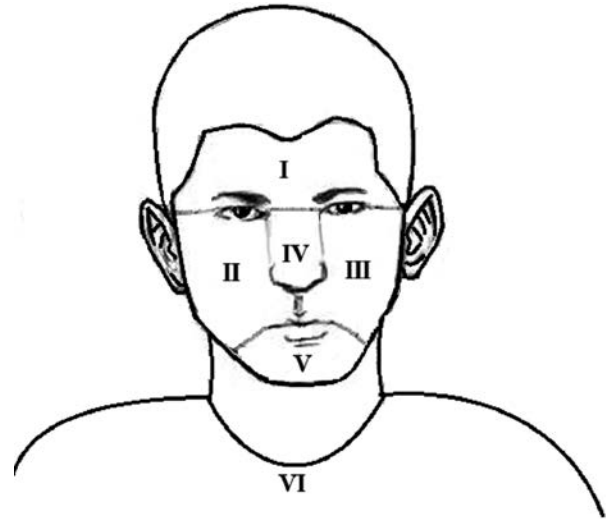


Fig. 4. The six locations (I-VI) of the global acne grading system (13).

dules within each template segment was counted. Hairline- and jaw line-defined perimeters of the face and the nose area were excluded. They assessed based on a five-grade classification of acne, which are very mild for patients having just a few comedones, mild for patients having more comedones and few papules and pustules, moderate for patients having many papules and pustules with a few nodules and very severe for patients having several comedones, papules, pustules and nodules.

In 1997, Doshi et al. (13) introduced a global acne grading system (GAGS). This system divided the face, chest and back into six locations (forehead, each cheek, nose, chin, chest and upper back) as shown in Fig. 4. The six locations are graded separately on a 0-4 scale depending on the most severe lesion within that location (0 = no lesions, 1 = comedones, 2 = papules, 3 = pustules and 4 = nodules). The score for each area is the product of the most severe lesion, multiplied by the area factor. These individual scores are then added to obtain the total score. For the total score between 1 and 18, the patient is classified as mild while for the total score between 19 and 30, the patient is classified as moderate. If the total score is between 31 and 38, then the grade is severe and if more than 39 then it is very severe as shown in Table 11.

For example, a patient has comedones at the forehead. Comedones are grade 1 as shown in Table 11, the forehead is in location I as shown in Fig. 4 and the factor for location I is 2. Thus, the local score is 2×1 , i.e., 2. Then on the right cheek, the patient has comedones, papules and pustules. Pustules are grade 3, the right cheek is in location II and the factor for location II is 2. Thus, the local score is 2×3 , i.e., 6. On the left cheek, patient has comedones, papules and pustules. Pustules are grade 3, the right cheek is in location III and the factor for location III is 2. Thus, the local score is 2×3 , i.e., 6. On the nose, the patient has comedones and papules. Papules are grade 2, the nose is in location IV and the factor for location IV is 1. Thus, the local score is 1×2 , i.e., 2. On the chin, the patient has papules and nodules. Nodules are grade 4, the chin is in location V and the factor for location V is 1. Thus, the local score is 1×4 , i.e., 4. On the chest and upper back, the patient has comedones and papules. Papules are grade 2, the chest and upper back are in location VI and the factor for location VI is 3. Thus, the local score is 3×2 , i.e., 6. The GAGS is the total of all local scores ($2+6+6+2+4+6=26$). Thus, from Table 11, the score of 26 indicates that the patient is moderate in terms of scale. A similar system was proposed by Dreno and colleagues in 1999 (9).

Again in 1998, the Leeds technique was revised by Brien and colleagues. The Leeds Revised Acne Grading System provides a photographic standard for acne grading of the face, back and chest (14). These representations were selected over 1000 photographs by an expert panel of three dermatologists and four acne assessors. There are

12 grades for the face and 8 grades for the upper chest and back (Table 12).

In 2008, Hayashi et al. (15) used standard photographs and lesion counting to classify acne into four groups. First, they classified acne based on the number of inflammatory eruption of half face. Second, they counted the lesions and divided the total number of lesions into four groups. For total number of lesions <5, grade is classified as mild and 6–20 as moderate. If the total number of lesions is between 21 and 50, it is in the severe group and more than 50 is very severe as shown in Table 13. Their judgments on severity grades were then compared with those of an expert panel of three dermatologists, who evaluated half-face photographs of the same patients.

Table 14 summarizes the acne assessment methods discussed in this section.

Table 15 provides a reference for the different types of acne grading system used in various countries in the world. We collected the following data from various publications as indicated by the references in Table 15.

Computational Methods for Assessment of Acne Lesions

Direct visual assessment and ordinary flash photography represents a normal clinical evaluation. However, both methods are compromised by viewer subjectivity; hence, the assessment of individual acne lesions and severity grading is not so accurate. Different dermatologists yield different assessments for the same patient and this is known as inter-observer reliability. But sometimes the same dermatologist also yields different assessments for the same patient on

different days. This is called intra-observer reliability. Besides this, the dermatologist does not have enough time to count acne lesions properly because they need to see many patients in a

TABLE 12. The grade based on a photographic standard (14)

Body part	Mild	Moderate	Severe
Face	Grade 1–Grade 4	Grade 5–Grade 8	Grade 9–Grade 12
Upper chest and back	Grade 1–Grade 3	Grade 4–Grade 5	Grade 6–Grade 8

TABLE 13. The grade based on a photographic standard and lesion counting (15)

Total number of lesions	Group
0–5	Mild
6–20	Moderate
21–50	Severe
> 50	Very severe

TABLE 14. Acne assessment method

Year	Acne assessment	Assessment method
1956	Pillsbury et al. (8)	Lesion counting
1958	James and Tisserand	Lesion counting
1966	Witkowski and Simons	Lesion counting
1971	Frank	Lesion counting
1975	Plewig and Kligman	Lesion counting
1977	Christiansen et al	Lesion counting
1977	Michaelson et al	Lesion counting
1979	Cook et al. (10)	Photographic
1984	Burke et al	Photographic
1985	Samuelson	Photographic
1996	Luckt and colleagues	Lesion counting
1997	Doshi et al. (13) (GAGS)	Lesion counting
1998	SC O'Brien and colleagues (Leeds)	Photographic
2008	Hayashi et al. (15)	Photograph and lesion counting

TABLE 11. The Global Acne Grading System (13)

Location	Factor (F)	Severity (S)		Local score (F×S)	Acne severity	
Forehead	2	0	Nil		Mild	1–18
Right cheek	2	1	Comedone		Moderate	19–30
Left cheek	2	2	Papule		Severe	31–38
Nose	1	3	Pustule		Very severe	>39
Chin	1	4	Nodule			
Chest and upper back	3					
		Total Score				

TABLE 15. Country and grading system

Country	Grading system
Hong Kong	Global Acne Grading System (GAGS) (16)
India	GAGS (17)
Japan	Hayashi et al (15)
Jordan	GAGS (18)
Korea	Korean Acne Grading System (19)
Malaysia	Leeds Grading System, GAGS (20)
Saudi Arabia	GAGS (21)
Turkey	GAGS (22)
United Kingdom	Leeds Grading System (23)
United States of America	Investigator's Global Assessment (24)

limited time. Counting is tedious because of various types of acne and the number of lesions present. Hence, they provide an approximate count leading to an approximate acne grade. Scientific researches in acne particularly those investigating the efficacy of treatment currently utilize subjective methods of clinical evaluation to assess response to therapy. These methods are subjected to inter- and intra-observer reliability, which may influence the research outcome. An objective, accurate and reliable assessment tool is essential to improve clinical evaluation. Therefore, researchers have proposed computational imaging methods for aiding in the acne clinical severity grading.

Fluorescence photography was proposed in 1996 to evaluate acne. Lucchina and colleagues selected 40 patients with mild to moderate acne vulgaris and took photographs using flash and fluorescence at baseline, 4, 8 and 12 weeks (11).

Equipment for flash photographs included a Minolta X-700 camera body (Minolta, Osaka, Japan) with a Tamron 90 mm macrolens (Tamron, Saitama, Japan) and a Vivitar series-I-28 to 105 mm macrolens (Vivitar, Oxnard, CA, USA). For fluorescence photograph, they used the same camera body with flash photograph and included a Kodak Wratten #4 filter (Rochester, NY, USA) on the lens to block all UV light and pass only visible light. Figure 5 shows the photograph of a subject with mild acne taken using flash and fluorescence photography.

In 1997, Phillips et al. (25) became the first group to study polarized light photography to assess the comedo counts and inflammatory acne lesion counts. They compared the acne assessment obtained from clinical evaluation with assessments from a photograph obtained with flash

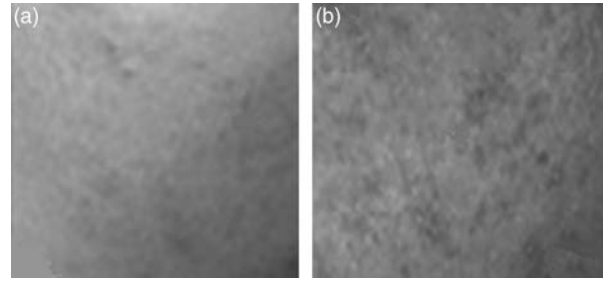


Fig. 5. Subject with mild acne on the left cheek (the darker areas in (b) correlate with closed comedones, papules, erythema and pigmentation) (11). (a) Flash photography (b) fluorescence image.

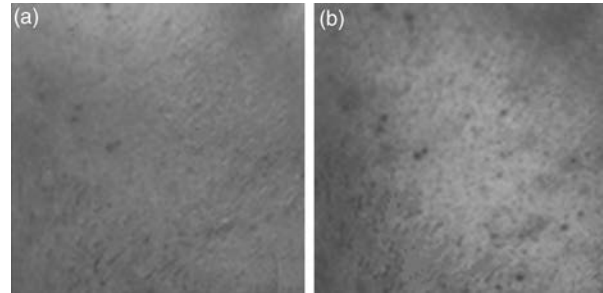


Fig. 6. Open comedones on the right cheek (visible in flash photograph but more clearly delineated in the perpendicular polarized light photograph) (25). (a) Flash photograph (b) perpendicular polarized light photograph.

photography and with perpendicular polarized light photography.

For flash photography, they used a Minolta X-700 with either a Tamron 90 mm macrolens fitted with a $\times 2$ tele-converter or a Vivitar Series 1 28–105 mm macrozoom lens to obtain standard photographs. For polarized light photography, they used a Minolta 80PX ring flash with a linear polarizer affixed to the surface of the flash head. A similar linear polarizer was placed in front of the camera lens.

Both flash and polarized used the same camera lens and body. Besides this, a photographic table was used to maintain the camera and flash positions over time. Full frontal pictures were taken with the patient looking directly into camera lens. The right and left sides of the face for standard and polarized light photographs were taken with the patient looking at 45° to the left or the right of the midline.

Figure 6 shows the comparison between flash photograph and perpendicular polarized light photograph. They enhanced the visualization of skin features, color and lighting and framing in perpendicular polarized photograph. As a result, comedo counts were easier.

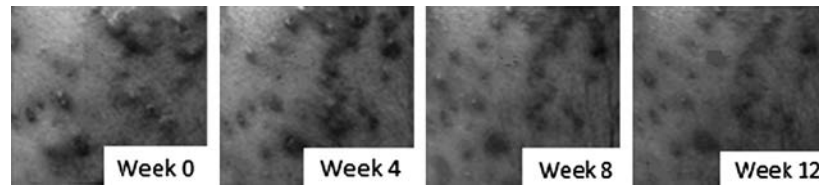


Fig. 7. Using the digital program, the region of interest (ROI) with the most significant acne lesions was selected. ROI at weeks 0, 2, 4, 6, 8, 10 and 12 was printed on an A4 photographic paper as template to count and characterize lesion types (27).

In 2001, Rizova and Kligman used both parallel and crossed polarizing light photography in combination with video microscopy and sebum production measurement. They also viewed the effects of adapalene gel 0.1% on inflammatory and non-inflammatory acne lesions. The parallel and crossed polarizing light photography, in combination with video microscopy and sebum production, measures the response of sebum to adapalene gel 0.1%. Sebum is an oily substance that may cause acne. Adapalene is effective in preventing the development of new lesions and good for treating inflammatory and non-inflammatory lesions. As a result, sebum secretion rates declined during treatment (26).

In 2008, Thy et al. (27) studied the computer-assisted alignment and tracking of acne. Images were taken using a digital camera. This technique combined digital photography with photo-editing software. The photographs taken every 2 weeks for 12 weeks used a Nikon D1 × digital camera (Tokyo, Japan) at a resolution of 1960×3008 pixels (5.9 megapixels) and a fixed reproduction ratio equivalent to 1:6 on a 35 mm film. Then, they used the software PICTURE WINDOW PRO 4.0 (Digital Light & Color, Belmont, MA, USA) for selected alignment.

A region of interest (ROI) with the most clinically major acne lesions was selected on 27 patients who have mild to moderate acne based on the Leeds technique. Each patient's dataset consisted of up to seven ROIs. The lesions were counted in each ROI and classified either as open or as closed comedones, papules, pustules and nodules. A ROI area of 400×400 pixels (2.8×2.8 cm of skins) was printed together on an A4 template (Fig. 7).

From the first appearance, they assigned numbers to each new lesion after tracking inflammatory lesions. Then, they were monitoring lesion growth through consecutive weeks. This technique eliminated photographic inconsistencies such as variability of camera angle and framing.

Another group of researchers exploited multispectral images (MSI) for the assessment of acne

grade. MSI is one that captures image data at specific wavelengths across the electromagnetic spectrum. MSI allows the extraction of additional information that the human eye fails to capture with its receptor for RGB. Multispectral is a good solution for color problems in medicine and it has significant impact in many fields including dermatology and dentistry (28).

In 2008, Fuji et al. (29) used the spectral information, for various types of acne skin lesions, acquired from the MSI of the lesion. A 16-band multispectral camera (16 band 12 bits, 2048×2048 pixels) was used with two tungsten lamps.

First, they removed the shade and gloss in preprocessing and then they used spectral information at each pixel for classification. The relative reflectance, which is the pixel value of the obtained object due to the 3D shape of object, involves the effects of shades and gloss. Gloss of dielectric material has the same spectral distribution as the illumination and the effect of gloss is eliminated with the projection. The multispectral signal of the resulting image is normalized with respect to the total intensity of each pixel so that the shades and shadows are removed.

They used a combination of several linear discriminant functions (LDFs) for acne lesion classification. They used 3 Fisher LDFs and 3 threshold values to consider three classes to classify acne types. The Fisher LDFs were calculated from both reddish papule and pustule, both pustule and scar and both reddish papule and scar, respectively. The threshold values for these LDFs were determined experimentally. MSI and the LDF classifier were able to differentiate several skin lesions such as comedo, reddish papule, pustule and scar.

In 2008, Bae et al. (30) introduced a multimodal facial color imaging modality for objective analysis of skin lesion. They used a conventional color image, parallel and cross-polarization color images and a fluorescent color image. They proposed fluorescent image analysis methods for the quantitative evaluation of sebum-related parameters such as pattern, area and density, average size

TABLE 16. Summarizing the imaging modalities for acne analysis

Year	Imaging modality	General approach	Specific method	Comments
1996	Fluorescence photography (11)	Comparing the counts of acne using flash and fluorescence photograph	Two filters were used for fluorescence photography for UVA transmittance and elimination of infrared light	Fluorescence photography appears to be a useful tool to chart the course of acne treatment
1997	Polarized light photography (25)	Comparing the acne assessment obtained from clinical with a photograph obtained from flash photography and perpendicular polarized light photography	The polarizing filter on the camera was oriented at a right angle with respect to the linear polarizer on the ring flash	Comedo counts were easier in a perpendicular polarized photograph than a flash photograph
2001	Parallel-polarized and cross-polarized photography with video microscopy and sebum production measurement (26)	The parallel and crossed polarizing light photography used	Combined with video microscopy and sebum production measurement to assess the response of sebum to adapalene gel 0.1%	They used multiple methods. Hence, this method cannot be used for real-time analysis
2008	Computer-assisted alignment and tracking of acne (27)	Used a digital photograph and select region of interest (ROI). Then, assigned numbers to each new lesion in ROI after tracked inflammatory lesions for every 2 weeks for 12 weeks	Combined with a software program with alignment capabilities	Count and characterize lesion types and monitoring acne lesion growth for 12 weeks
2008	Multispectral images (MSI) (28)	Applied a combination of several linear discriminant functions (LDFs) classifier with MSI	Used Fisher LDF to classify the different acne types	Classified comedo, papule, pustule and scar based on color image

and diameter of spots. Table 16 summarizes the various computational methods based on imaging techniques for the assessment of acne lesions.

Potential Computational Methods for Acne Grade Assessment

Various methods and techniques developed for skin analysis can be used to assess the grade of acne vulgaris quantitatively.

Xu and colleagues presented an automatic method for the segmentation of images of skin lesions in 1999. This method reduces a color image into an intensity image and approximately segments the image by intensity thresholding. After that, it improves the segmentation using image edges. They used double thresholding for focus on an image area where a lesion boundary potential exists and used image edges to restrict the lesion boundary.

They developed a three-step segmentation, which is preprocessing, initial segmentation and region refinement. In the first step, which is preprocessing, a color image was transformed into an intensity image. Thus, the intensity at a pixel shows the color distance of that pixel, with the color of the background taken to be the median color of pixels in small windows in the four corners of the image.

The second step is initial segmentation, where the threshold value is used to find approximate lesion boundaries. A threshold value is determined from the average intensity of high-gradient pixels in the intensity image obtained. The last step is refinement, where a region boundary is refined using edge information in the image. This involves initializing a closed elastic curve at the approximate boundary and shrinking and expanding it to fit to the edges in its neighborhood.

The result of segmentation from 20 selected images shows an average error to be the same as that of four experts who segmented the lesion boundaries of images manually. They proposed three parameters, which are the standard deviation of the Gaussian smoother, the threshold value needed to find the initial lesion boundaries and the sharpness of color changes across lesion boundaries, respectively (31).

In 2003, Schmid-Saugeon et al. (32) used a computer-aided diagnosis system to assist the physician in different analysis steps, such as the skin lesion boundary detection and quantification of diagnostic features, the classification into different types of lesions, the visualization, etc.

Lesion detection results were validated by expert dermatologists, who also provided hand-drawn boundaries of the lesions. These reference

TABLE 17. Comparison of skin detection methods

Types of method	Details of the method	Advantages	Disadvantages
Skin-color thresholding	Remove parts of the image that fall within a specified color range and detect objects of consistent color values	Very fast and requires little storage space	The system lacks flexibility
Neural network classifier	Interconnected group of natural or artificial neurons that uses a mathematical or a computational model for information processing based on a connectionistic approach to computation	Can be used to model complex relationships between inputs and outputs or to find patterns in data	Acquire decision boundaries from training data and take long time to process
Maximum entropy classifier	Trained to identify and classify the predicates' semantic arguments together	Provides a probability of assigning a classification being correct	Has to deal with six color histograms owing to the involvement of the neighboring pixels in the process
Bayes classifier	A simple probabilistic classifier based on applying Bayes' theorem with strong independence assumptions	Requires a small amount of training data to estimate the parameters necessary for classification. Fast to train, fast to evaluate	Not capable of solving more complex classification problems

boundaries were not used as a gold standard, but allowed statistical determination of the accuracy of the boundaries provided by computerized techniques. They showed the dermatologists were not able to reproduce their results, and that the boundaries of any expert taken alone showed higher divergence from those of the set of remaining experts than the automatic techniques.

Feature extraction is restricted in this paper to the quantification of degree of symmetry, even though it is clear that many other features will be necessary for a complete diagnosis system. The symmetry quantification step provides a six-dimensional feature vector that can be used to classify pigmented skin lesions as being benign or malignant.

In 2008, Masood and colleagues introduced an unsupervised color segmentation procedure for skin lesion classification. They evaluated based on different color models and selected the most appropriate model for representing the skin lesions. There are two steps for color segmentation, which are coarse with an optimal threshold of the CIE color model and fine segmentation with *K*-means clustering technique (33).

In coarse segmentation, they obtained the background color of an image and selected four windows of 4×4 pixels from four corners of image. Background color was chosen from the median color. The threshold and number of regions are determined applying scale-space filtering to a histogram of the color components using the optimal threshold. Median filtering with 5×5 neighborhood and hole-filling were used.

The *K*-means clustering technique is used to segment those pixels that are not segmented in

coarse segmentation. It classifies image pixels into classes or groups depending on the Euclidean distance between the pixels and class means based on the nearest-neighbor approach.

Skin detection is a common preprocessing step for analyzing images or videos of humans. It aims to track the human body for further recognition and its application includes face detection and recognition, image content classification, gesture analysis, etc. Skin detection method includes the Bayes classifier, maximum entropy classifier, neural network classifier, skin-color thresholding, etc. Table 17 shows a comparison of skin detection methods.

Conclusion and Recommendation

Acne is a very common human skin disease that affects individuals around the world. The grading system is one of the main issues because there is no global standardized grading. Additionally, grading is a subjective measure that varies from one dermatologist to another (inter-rater reliability) and it may also vary for the same dermatologist at different times for the same patient (intra-rater reliability). This is due to the fact that counting is a tedious process because of various types of acne as well as the number of lesions. Hence, dermatologists provide an approximate count leading to an approximate acne grade.

In this paper, the detailed analysis of acne grading system as well as measurement has led to the identification of issues related to acne that need to be addressed for effective acne treatment. The issues include inter- and intra-rater reliability

and selection of an acne grading system. Computational methods based on imaging techniques can be used to address some of these issues, especially inter- and intra-rater reliability directly. Uniform acne grading computational assessment will also lead to the elimination of inter- and intra-rater reliability, which in turn leads to effective acne treatment and hence contributes directly to the existence of various grading systems.

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Address:

*Aamir Saeed Malik
Department of Electrical and Electronics
Engineering
Universiti Teknologi PETRONAS
Perak 31750
Malaysia
e-mail: aamir_saeed@petronas.com.my*