35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

A Quantitative Technique for Assessing the Change in Severity over Time in Psoriatic Lesions Using Computer Aided Image Analysis

Juan Lu[1], Ed Kazmierczak[1], Jonathan H. Manton[2], and Rodney Sinclair[3]

Abstract— **Psoriasis is a chronic skin disease affecting an estimated 125 million people worldwide. One of the key problems in the management of this condition is the objective measurement of lesion severity over time. Currently, severity is scored by clinicians using visual protocols leading to intra and inter observer variability that makes measurement of treatment efficacy subjective. In this paper, an automatic computer aided image analysis system is proposed that quantitatively assess the changes of erythema and scaling severity of psoriatic lesions in long-term treatment.**

The algorithm proposed in this paper works on 2D digital images by selecting features that can be used to accurately segment erythema and scaling in psoriasis lesions and assess their changes in severity, according to the popular psoriasis area and severity index (PASI). The algorithms are validated by developing linear models that correlate well with changes in severity scores given by dermatologists. To the best of our knowledge, no such computer assisted method for psoriasis severity assessment in a long-term treatment exists.

I. INTRODUCTION

Psoriasis is a chronic skin disease with no known cure and there are currently an estimated 125 million people worldwide suffering from this disease. A psoriatic lesion manifests as red inflamed skin (erythema) typically surrounding, or partially surrounding, scaly flaky skin (scaling).

Pills, balms and radiation treatments are available to control the symptoms of psoriasis, but there is no generally accepted standard treatment for psoriasis. Different dermatologists will treat the same symptoms differently. Further, due to the chronic nature of psoriasis, treatments usually span long time frames. The symptoms may change with remission, relapse or rebound. To monitor psoriasis, lesions need to be evaluated over a time period [1]. Time-based evaluation will also aid research into psoriasis treatment and clinical practice by facilitating objective treatment comparisons to determine the most effective treatment methods.

This paper presents a computer aided image analysis system that to the best of our knowledge is the first to automatically evaluate the changes in severity of erythema and scaling in a long-term psoriasis treatment. Existing methods either manually record the changes or are only applicable to a short-term change assessment.

[1]J. Lu and E. Kazmierczak is with the Department of Computing and Information Systems, University of Melbourne, Victoria 3010, Australia jualu@student.unimelb.edu.au, edmundak@unimelb.edu.au

[2]J. Manton is with the Department of Electrical and Electronic Engineering, University of Melbourne, Victoria 3010, Australia jmanton@unimelb.edu.au

[3]R. Sinclair is with the Department of Medicine (Dermatology), University of Melbourne and St. Vincent's Hospital Melbourne, Victoria, 3065 Australia rodney.sinclair@unimelb.edu.au

Currently, dermatologists monitor changes of psoriasis by recording psoriasis severity scores over time. A widely used severity scoring system is the PASI score, which requires estimates of the percentage of skin area covered by psoriatic lesions and grades the severity of erythema and scaling. Table I illustrates the PASI scores of erythema and scaling severity for a number of different lesion samples.

PASI scores for erythema and scaling are currently estimated visually by dermatologists, however, doing this results is unavoidable inter- and intra- observer variation. The aim of this research is to develop a reliable change assessment system to quantitatively assess the changes of erythema and scaling severities of psoriatic lesions.

Computer-aided analysis has been introduced into the area of psoriasis severity diagnosis for a number of decades, but only a very few systems have been implemented that focus on analysing the changes in psoriasis lesions. The only system so far is given in [2], where lesion changes are analysed through lesion image subtraction after registering images of the same lesion. The registration is implemented based on an assumption that in the treatment the psoriatic lesion boundaries do not change and the changes only happen inside the lesion. However, the assumption is only valid for a short term treatment. In long term treatments, psoriatic lesions do not only change within their boundaries, but also the boundary itself changes. Thus change analysis through image registration of the lesions is not suitable for comparisons in chronic treatment.

In this paper, we propose a set of features for assessing changes in psoriasis severity. The features are based on our previous work on erythema segmentation and scaling segmentation [3], [4]. The consistency between the features for assessing changes in severity and the PASI scores assigned by clinicians is validated using multiple linear regression analysis.

II. METHODS

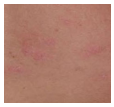
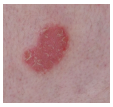
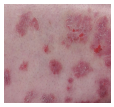
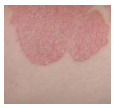
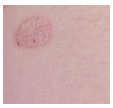
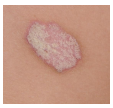
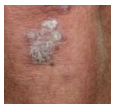
A. Erythema Segmentation and Scaling Segmentation

Observe from Table I that the severity of erythema and scaling is closely related with the composition of the lesion, and consequently that changes in severity are also related to changes in the composition of the lesion. Given a 2D image of a psoriasis lesion, the first step is to segment the elements of the psoriasis lesion, and in particular, to segment erythema and scaling within a lesion. In our work this is done separately. Segmenting out erythema and scaling allows the calculation of erythema area, scaling area and the whole

978-1-4577-0216-7/13/$26.00 ©2013 IEEE

TABLE I

PASI ERYTHEMA AND SCALING SEVERITY SCORING

Scores	1	2	3	4
Erythema Scoring	Light red	Red, but not dark red	Dark red	Very dark red
Erythema Images				
Scaling Scoring	Fine scaling covering part of the lesion	Fine to rough scaling covering a large part of the lesion	Rough, thick scaling covering a large part of the lesion	Very rough, very thick scaling totally covering the lesion
Scaling Images				

lesion area. Determining the lesion area is the first step towards the assessment of severity changes.

In our previous work [3], an algorithm for segmenting erythema from normal skin is given using a skin decomposition followed by a pixel-based classification scheme. It is assumed that the melanin pigment and haemoglobin pigment, which cause variation of skin colours, are mutually independent. Considering the optical deviation in digital imaging process, a skin colour can be expressed as a linear combination of the melanin and haemoglobin components in a log RGB colour space. In the skin decomposition stage, the haemoglobin component and the melanin component are extracted using an independent component analysis. A simple model of skin colour in terms of the two components is given by:

$$L_{x,y} = c^m q^m_{x,y} + c^h q^h_{x,y} + \Delta \tag{1}$$

where $L_{x,y}$ is a skin colour at coordinate (x,y) in the log RGB colour space, c^m and c^h are the extracted melanin and haemoglobin basis vectors, $q^m_{x,y}$ and $q^h_{x,y}$ are the quantities of each pigment for the skin colour, and Δ is a constant vector that accounts for other skin pigments and skin structure. The $q^m_{x,y}$ and $q^h_{x,y}$ are used as a pair of erythema descriptors in a support vector machine (SVM) to separate erythema from normal skin. This segmentation algorithm achieves a sensitivity of 0.9532 and a specificity of 0.7501 [3].

In our previous work, scaling is segmented from erythema and normal skin using another pixel-based classification based on features described later [4]. The first feature is derived by using a scaling colour contrast filter and is used to heighten the contrast between the white or creamy scaling pixels and the surrounding red erythema pixels. The other feature is constructed through a bank of Gabor filters, and is used to differentiate the rougher scaling textures in the image from smoother normal skin.

In the Gabor feature construction step, a bank of 24 Gabor filters are designed with three different spatial frequencies and eight equal-interval rotation angles that respond well in a variety of skin and scaling texture conditions. A *Gabor feature* is defined as the sum of the squares of the Gabor filter energies that have been smoothed using a hyperbolic tangent and a mean filter. This technique accentuates the textures whose orientation and frequency are between the orientations and the spatial frequencies in the bank of Gabor filters, while suppressing the response of the textures whose frequency are beyond the spatial frequencies. Scaling is identified using the Gabor feature together with the response of scaling colour contrast filter in a SVM smoothed by a Markov random field (MRF), that takes structure of the images into account and properly classifies any pixels misclassified by the SVM. The sensitivity of this classification is 0.7229 and the specificity is 0.8946 [4].

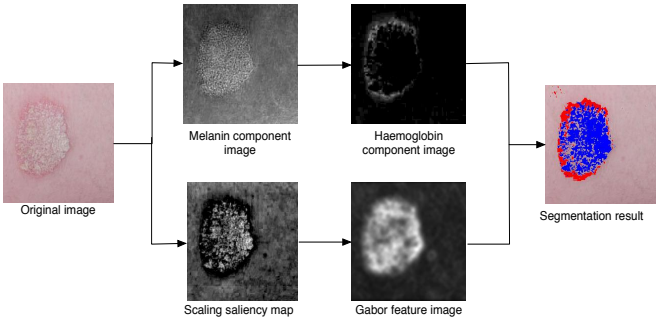


Fig. 1. Segmentation of erythema and scaling: the classified erythema pixels are marked in red and the classified scaling pixels are marked in blue.

The whole process of erythema segmentation and scaling segmentation for a psoriatic lesion is shown in Fig. 1

B. Severity Change Features of Erythema and Scaling

We use the features from the segmentation algorithm and the segmentation results to quantify the change in lesion severity and specifically the melanin component q^m, the haemoglobin component q^h, and the Gabor feature used in the segmentation algorithm, as well as the erythema area and the scaling area derived from the segmentation results. These features are directly related to severity scoring as used in PASI (see Table I).

Changes in lesion severity are described by a subtraction between the severity features of a lesion at one time point and the features of the same lesion at another time point. A general severity change function $D(X)$ is expressed as:

$$D(X) = X_{\tau 2} - X_{\tau 1} \tag{2}$$

where X_{τ_2} is the severity feature at the second time point, and X_{τ_1} is the severity feature at the first time point.

For assess the erythema severity, we only need to consider the haemoglobin and melanin components [3]. The erythema severity features $\nabla(\overline{q^h})$ and $\nabla(\overline{q^m})$ are defined as the differences in these components between erythema and normal skin.

$$\nabla(\overline{q^h}) = \overline{q^h_E} - \overline{q^h_S}; \quad \nabla(\overline{q^m}) = \overline{q^m_E} - \overline{q^m_S} \tag{3}$$

where $\overline{q^h_E}$ and $\overline{q^h_S}$ are the mean value of the haemoglobin quantities in erythema and normal skin respectively, and $\overline{q^m_E}$

and $\overline{q_S^m}$ are the mean value of the melanin quantities for erythema and normal skin respectively. The reason of using difference of means is that dermatologists typically score erythema severity by comparing the average erythema colour with the surrounding average normal skin colour.

The change in erythema severity within a lesion can now be defined by the **erythema severity change feature set** C_{Erythema}:

$$C_{\text{Erythema}} = \{D(\nabla\overline{q^h}), D(\nabla\overline{q^m})\} \quad (4)$$

From table I, we observe that the scaling severity depends on two factors: the roughness of the scaling and the area of scaling relative to the whole lesion. The change in scaling severity can be modelled by the **scaling severity change feature set** C_{Scaling}:

$$C_{\text{Scaling}} = \{D(r), D(\overline{g})\} \quad (5)$$

where r and $\overline{g}$ are scaling severity features: r describes the relative scaling area defined as the ratio of the scaling area to the whole lesion area, and $\overline{g}$ describing the roughness degree is calculated as the mean Gabor feature values of the scaling (see also [4]). $D(r)$ and $D(\overline{g})$ is about the changes of relative scaling area and roughness degree respectively.

III. Experimental Validation

Psoriasis skin images are collected from the Skin & Cancer foundation Victoria, where the imaging environment is carefully set to ensure controlled illumination and include various skin types from Asian and Caucasian ethic backgrounds.

The images for a specific lesion were collected at two different time points and given PASI scores by two dermatologists. Only those images that were given identical PASI scores by the two dermatologists for both time points were selected. For comparisons with the algorithms, the ground truth is chosen to be the difference in PASI severity scores between the two time points for each lesion. We note that a straight subtraction of severity scores between two time points may yield a negative value indicating a decrease in severity, or a positive value indicating an increase in severity. The situation is symmetrical for our analysis and only severity decrease is considered in the experiment. Multiple linear regression is used to analyse correlation between the severity change features and the severity change scores.

Table II shows the results for 17 images with erythema severity changes and Table III shows the results for 14 images with scaling severity changes. In both cases, severity change of 2, severity change of 1 and no severity changes are included.

In Table II, score before and the score after are the severity scores given by dermatologists at the fist time point and the second time point respectively. Besides, the index of image pairs, the changes score that is a subtraction of the score before from the score after, the corresponding erythema severity change features: $D(\nabla\overline{q^h})$ and $D(\nabla\overline{q^m})$ are given.

It is observed that the decrease of erythema severity is companied by decrease of the mean haemoglobin difference $\nabla\overline{q^h}$ and increase of the mean melanin difference $\nabla\overline{q^m}$. When

TABLE II

Erythema Severity Change Scores with the Severity Change Features and the Before-after Severity Scores

Index	Score before	Score after	Changes score	$D(\nabla\overline{q^h})$	$D(\nabla\overline{q^m})$
1	4	2	-2	-3.203	9.663
2	3	1	-2	-2.466	15.795
3	3	2	-1	-2.238	4.909
4	3	2	-1	-1.925	4.909
5	3	2	-1	-1.374	0.033
6	3	2	-1	-0.773	15.515
7	4	3	-1	-0.666	17.174
8	2	2	0	-0.740	8.120
9	2	2	0	-0.598	8.238
10	2	2	0	0.203	4.547
11	2	2	0	1.243	13.112
12	2	2	0	2.784	9.848
13	3	3	0	-0.592	10.224
14	3	3	0	0.063	13.077
15	3	3	0	0.236	6.545
16	3	3	0	0.299	10.854
17	3	3	0	3.165	18.355

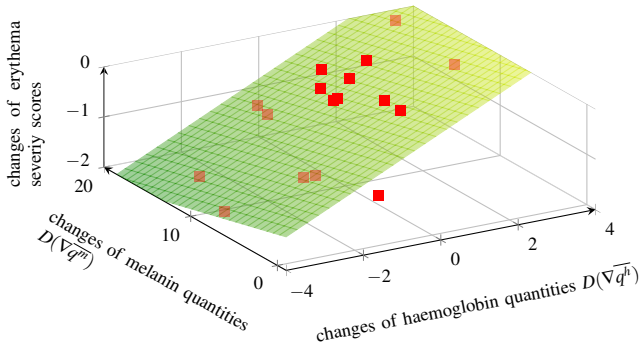


Fig. 2. Distribution of erythema severity change features in Table II and the severity change scores.

the erythema severity does not change, both $\nabla\overline{q^h}$ and $\nabla\overline{q^m}$ may increase or decrease. Furthermore, there is no clear relationship between values of the severity change features and the erythema severities at the start time point.

The multiple linear regression model is built as:

$$S_{\text{Erythema}} = 0.3653D(\nabla\overline{q^h}) - 0.0468D(\nabla\overline{q^m}) + 0.0824 \quad (6)$$

where S_{Erythema} is the estimated erythema severity change scores. The statistical R^2 value, which indicates the correlation of the estimated severity change score and the actual score, is 0.6747. The p-value is 0.0004, which is much less than the significance level 0.05.

Fig. 2 shows distribution of the erythema severity change features with severity change scores. The estimated erythema severity change score S_{Erythema} is illustrated with the green-yellow plane.

The parameters of the linear regression model indicate the linear relationship between erythema severity change features and the changes in erythema severity scores. Decreasing the mean haemoglobin difference has a greater effect on the

TABLE III

SCALING SEVERITY CHANGE SCORES WITH THE SEVERITY CHANGE FEATURES AND THE BEFORE-AFTER SEVERITY SCORES

Index	Score before	Score after	Change score	$D(r)$	$D(\overline{g})$
1	4	2	-2	-0.087	-0.105
2	2	1	-1	-0.512	-0.100
3	2	1	-1	-0.222	-0.237
4	2	1	-1	-0.045	-0.109
5	3	2	-1	-0.323	-0.132
6	4	3	-1	-0.164	-0.021
7	1	1	0	-0.006	0.150
8	2	2	0	0.039	-0.014
9	2	2	0	0.050	-0.218
10	3	3	0	-0.053	0.043
11	3	3	0	-0.050	0.119
12	3	3	0	0.031	-0.061
13	3	3	0	0.052	0.052
14	3	3	0	0.068	-0.133

decrease of erythema severity than an increase in the mean melanin difference. This fits the fact that the haemoglobin component contributes to the redness of the skin, while the melanin component causes yellowish to the skin. The melanin component slightly effects the severity changes due to its indirect effect.

Table III shows the index of image pairs, the score before, the score after, the scaling severity change score, and the corresponding severity change features: $D(r)$ and $D(\overline{g})$. It is clear that decrease of the scaling severity scores changes with the decrease of relative scaling area r and the roughness degree $\overline{g}$, and the severity scores at the before time do not affect the change quantities of the severity features.

The multiple linear regression model of scaling severity changes is built as:

$$S_{\text{Scaling}} = -0.2373 + 1.9711D(r) + 1.6613D(\overline{g}) \qquad (7)$$

where S_{Scaling} is the estimated scaling severity change score. The R^2 of this model is 0.4255 and the p-value is 0.0474.

Fig. 3 presents distribution of the scaling severity change features with the severity change scores. The plane of estimated scaling severity change score S_{Scaling} is drawn with a green-yellow colour.

Observed that the coefficients of $D(r)$ and $D(\overline{g})$ in Eq. 7 are quite near, it implies that the changes of scaling severities are nearly equally affected by the changes of relative scaling area and the changes of roughness degree. This observation matches the scaling scoring fact, where relative scaling area and the scaling roughness degree are considered together to decide the scaling severity.

The low R^2 value is due to the severity change features with a two-score change. The residual of this observation is -1.418, while the residuals of the rest observations are between ± 0.5. This is because in the selected image pair the higher scaling severity score lesion with a 4 score is mostly covered by scaling that displays itself as a smooth plaque. The Gabor feature is not good at differentiating this type of roughness changes. Fig. 4 shows the pair of the images.

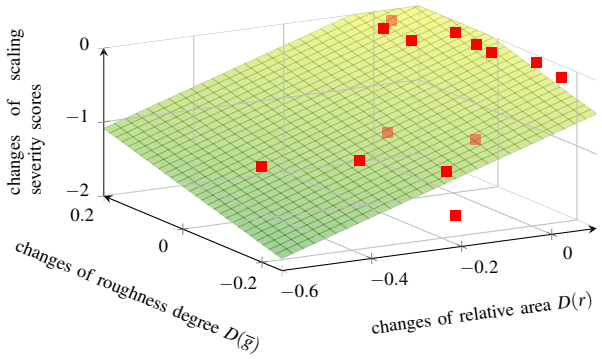


Fig. 3. Distribution of scaling severity change features in Table III with the severity change scores.

(a) (b)

Fig. 4. The selected pair of images with severity change of 2: (a) A psoriatic lesion with scaling severity 4; (b) The lesion in (a) evolved to the degree with scaling severity 2.

IV. CONCLUSIONS

In this paper, a procedure to quantify the changes of erythema severity and scaling severity is presented. The erythema severity change features and the scaling severity change features are developed according to PASI severity scoring instructions. Severity change features determined by the algorithms are strongly correlated with the PASI severity scores given by dermatologists, as indicated by the multiple linear regression analysis. Moreover, the algorithm and the linear models show promise for automatically quantifying severity changes in psoriasis lesions. In future, we will further investigate the severity change features, especially the roughness features in scaling, as well as collecting more lesion samples to explore relationships between the severity features resulting and PASI severity scores, and to improve the result of the severity change quantification.

ACKNOWLEDGMENT

The authors would like thank to Skin & Cancer Foundation Victoria, Australia and St. Vincent's Hospital Melbourne for support of the research.

REFERENCES

[1] L. Naldi and D. Gambini, "The clinical spectrum of psoriasis," *Clinics in Dermatology*, vol. 25, no. 6, pp. 510–518, 2007.

[2] D. D. Gomez, C. Butakoff, B. Ersbll, and J. M. Carstensen, "Automatic change detection and quantification of dermatological diseases with an application to psoriasis images," *Pattern Recognition Letters*, vol. 28, no. 9, pp. 1012–1018, 2007.

[3] J. Lu, J. Manton, E. Kazmierczak, and R. Sinclair, "Erythema detection in digital skin images," in *Image Processing, 2010. 17th IEEE International Conference on*, 2010, pp. 2545–2548.

[4] J. Lu, E. Kazmierczak, J. Manton, and R. Sinclair, "Automatic segmentation of scaling in 2D psoriasis skin images," *Medical Imaging, IEEE Transactions on*, vol. 32, no. 4, pp. 719–730, 2013.