Texture analysis of digital skin images for assessing the severity of dermatoses

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Here, we propose a method for the quantitative assessment of the clinical severity of inflammatory dermatoses based on the analysis of digital RGB images of the pathological area. It involves the extraction of the texture features to monitor the dynamics of the pathology development. The proposed approach was tested in a rat model of imiquimod-induced psoriasis-like skin inflammation by comparing the extracted texture features and the resulting composite index with an overall clinical index, which reflected morphological changes in the skin. The inflammatory model was formed for six days with simultaneous recording of the experimental skin areas using a standard digital camera under fixed imaging conditions, as well as visual assessment of the severity of inflammation based on the standard PASI scoring system. In addition, histological examination was performed to confirm the formation of the psoriasis-like skin inflammation. To quantitatively characterize the images, 87 texture features were calculated, including first- and second-order ones as well as Haralick features. Based on correlation analysis, the six most informative features were selected, and a composite index was further calculated from them by the means of principal component analysis. This index corresponded to the first principal component (PC1) and demonstrated a good correlation with the cumulative PASI scores ($r = -0.82$). The obtained results indicate that texture analysis of standard RGB images holds great promise for objective and reproducible quantitative assessment of the severity of inflammatory dermatoses in preclinical and clinical studies.

Keywords: texture analysis, Psoriasis Area and Severity Index, PASI, automated diagnostics, inflammatory dermatoses, dermatology.

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Introduction

Despite continuously improved diagnosis and treatment methods, skin diseases remain widely occurring in the world population. According to the last report of the Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing, in 2024, the morbidity pattern of the population of Russia associated with unsatisfactory drinking water quality, skin and subcutaneous tissue diseases ranked third in the absolute number of additional cases 13 % (184100 cases), while in the morbidity pattern of the child population, this disease class ranked second — 18.9 % (93300 cases) [1]. Skin diseases are the world's fourth prevailing cause of all human diseases covering almost one third of the world population [2].

According to the bibliometric analysis, atopic dermatitis and psoriasis in the skin disease pattern account for the largest percentage of the global burden of disease (22 % and 11 %, respectively) [3]. Heterogeneity of the pathogenetic mechanisms of the disease development, a wide range of triggers, social significance of the disease, a variety of clinical forms, large lesion areas, involvement of functional and problem sites into the inflammation process, treatment resistance occurring in some cases, low patient compliance with outpatient therapy provide the basis for optimizing the treatment of psoriasis and atopic dermatitis [4,5].

Various noninvasive methods for skin condition monitoring, including transepidermal water loss measurement [6], diffuse reflectance spectroscopy [7], optical coherence tomography [6], Raman scattering spectroscopy [8], optoacoustic mesoscopy [9], etc. [10], play an important role both in the pathogenesis study of such multifactorial dermatoses and in the study of new treatment approaches. These methods allow for real-time evaluation of the skin barrier function, the severity of inflammation, the degree of vascularization and remodeling of the dermal matrix, as well as the response to therapy. The introduction of biophotonics methods into dermatological practice has significantly expanded a set of objective biomarkers of skin condition, reducing the dependence of clinical decisions on physicians subjective visual assessment [11–13]. The rapid growth of digital data volumes obtained using these visualization methods requires the development of standardized mathematical image processing algorithms aimed at automated selection of informative features and the formation of integral quantitative indices for assessing the severity of skin diseases. Texture analysis of digital skin images is one of the promising analytical instruments in this context [14–16] which allows for quantitative description

of spatial heterogeneity of brightness and optical density distribution associated with inflammation, impaired keratinization processes, and vascular remodeling. The use of such methods offers the opportunities for improving the objectivity of monitoring the course of dermatoses and automated assessment of the effectiveness of therapy, and in future for integration of machine learning methods and personalized predictive models into routine dermatological practice.

Despite the widespread implementation of various optical imaging and spectroscopy techniques in routine clinical practice, scoring systems are the basic and most well-established approach to evaluating skin disease severity. Visual assessment using special indices developed by the international medical community is the „gold standard“ or determining the severity of dermatoses: for example, the SCORAD index (Scoring of Atopic Dermatitis) used for atopic dermatitis severity evaluation [17] or PASI (Psoriasis Area and Severity Index) for assessing the severity of psoriatic skin lesion [18]. However, the fact that scoring in this case is performed by qualified clinicians does not completely exclude the subjectivity of such assessment.

The rapid development of biomedicine and resulting increase in pharmaceutical product range at various clinical study phases dictate the need to ensure uniformity of testing conditions for pharmaceutical substances under development. Increased objectivity of dermatosis severity evaluation in the study of therapeutic effectiveness of new dermatological medications plays an important role in solving this problem. In this regard, photometry and texture analysis of digital images appear to be promising methods [14–16]. A separate class of such approaches is based on the analysis of conventional clinical photographs. Unlike hi-tech imaging techniques such as optical coherence tomography or optoacoustic mesoscopy, digital image texture analysis does not require any specialized expensive equipment and can be implemented using standard digital cameras or even smartphones [19]. This makes it the most available tool for routine clinical practice and large-scale multicenter research [20], including clinical trials.

The purpose of this study was to develop and test an approach to the quantitative evaluation of psoriasis-like dermatitis severity on the imiquimod-induced skin disease model in laboratory rats on the basis of digital RGB image texture analysis. For this, informative texture features have been extracted and selected followed by building integral index using the principal component method and a comparison of its dynamics with the cumulative clinical PASI index.

Materials and methods

Laboratory animals

All experimental procedures were performed in male albino rats of 5 months of age weighing 300 ± 25 g. The study was carried out at the Animal Facility of the Saratov State Medical University (SSMU) named after V.I. Razumovsky, Ministry of Health of the Russian Federation. The animals were used in accordance with the Declaration of Helsinki on Animal Use in Research. All animals were handled in full compliance with the research protocol approved by SSMU Ethics Committee (protocol № 8 as of 04.02.2025).

The study involved 20 laboratory rats with a dermatitis model and 2 healthy rats (control). Animals were kept in individual cages in controlled ambient conditions (at $20-26\,^{\circ}$C) with 12 hour lighting cycle. Food and water were provided *ad libitum*.

Formation of the dermatitis model

The study used a psoriasis-like skin inflammation model. Imiquimod, an immunomodulator, was used as a pathology inducer. A day before the model formation started, hair was removed from the back of the laboratory animals using a trimmer without damaging the skin. The experimental pathology was formed by topical application of Keravort cream (Glenmark, India) containing 5 % imiquimod to an area on a rat's back in accordance with the standard protocol [21]. More precisely, 125 mg of Keravort was applied daily during 5 days to a test skin area of approximately $16\,\text{cm}^2$ ($4\,\text{cm} \times 4\,\text{cm}$).

The imiquimod-induced model was chosen due to its capability to reproduce main external and morphological signs of human plaque psoriasis, including erythema, scaling and epidermis thickening, as well as typical histological changes in the form of acanthosis, parakeratosis and pronounced inflammatory infiltration associated with activation of the IL-23/IL-17 axis [22]. It should be noted that this model refers to acute inflammatory models and doesn't fully reflect chronic relapsing course of psoriasis in humans. However, it ideally suits the development of digital skin image analysis algorithms to assess the severity of external dermatological signs of psoriasis.

Monitoring of pathology formation and assessment of the severity of its clinical manifestations

Severity of imiquimod-induced psoriasis-like skin inflammation was visually assessed using the psoriasis area and severity index (PASI) adapted for animals. Animals were examined before the initial application of the pathology inducer and then daily during 6 days. According to standard protocols [23], the disease course was evaluated by the severity of erythema, scaling and induration of the damaged skin area on rat's back on a scale of 0 to 4, where 0 is no manifestation (normal), 1 is minor manifestation, 2 is moderate manifestation, 3 is pronounced manifestation, 4 is severe manifestation. Damaged skin area was not measured in that case because the disease region was fixed and defined by the imiquimod application area.

To improve the evaluation accuracy and objectivity, scoring was performed by two independent experts and then the mean score was calculated. As a result of summing up the scores of erythema, scaling and induration, cumulative

scores were further obtained, illustrating the integral severity of psoriasis-like dermatitis. Consistency of evaluations from two experts was additionally evaluated using the weighted Cohen's Kappa coefficient for an ordinal scale of 0 to 4 (for each feature separately).

Photographs of the damaged skin area in laboratory animals were also taken using a digital 8-bit RGB camera. Digital images were obtained in fixed conditions: the camera was placed on a tripod, constant distance to the object and camera angle were kept, and stable lighting was used. Images were acquired with the camera in manual mode (fixed ISO/exposure/aperture, disabled autoexposure and automatic white balance) to reduce interday variability of image brightness characteristics and to forgo color calibration. Further, custom-tailored software in Python was used for the texture analysis of the obtained images. A region of interest (ROI) corresponding to the imiquimod application site was formed for the analysis. ROI was selected semi-automatically — a fixed 3×3 cm square positioned using anatomic landmarks in such a way as to cover a skin area corresponding to the dermatitis inducer application. To evaluate the texture properties of the disease site, images were divided into three color channels: red (R), green (G) and blue (B). For each channel, second-order statistical features were calculated on the basis of the gray level co-occurrence matrix (GLCM) calculated for five pixel spacings ($d = 1, 5, 9, 15, 29$ pixels) and four angles (0°, 45°, 90°, 135°). GLCM was built for ROI as the $P(i, j, d, \theta)$ matrix whose elements are equal to the number of pixel pairs with the brightness levels i and j separated by the displacement vector set by the pixel spacing d and direction θ. Before feature extraction, the matrices were normalized (transition to probabilities) and averaged over four directions (0°, 45°, 90°, 135°) to reduce the dependence on texture orientation because skin structures have no selected preferable direction. The following texture properties were extracted from the averaged GLCM: contrast, dissimilarity, homogeneity, energy and correlation. Moreover, for each channel in the disease region, additional first-order statistical characteristics were calculated such as mean brightness (mean), standard deviation (std), kurtosis and brightness skewness.

A set of pixel spacings $d = 1, 5, 9, 15, 29$ was selected for texture analysis on several spatial scales: small d reflected micrononhomogeneities (roughness, minor scaling), large d reflected macrostructural changes (scale/crust accumulation, large-scale brightness speckling). A pixel size determined by a calibration object was 77 μm. Thus, textures on a scale from several hundreds of micrometers to 2 mm were analyzed. Such selection ensured feature sensitivity to small and large structural changes in skin during dermatitis progression.

Thus, a texture feature vector that quantitatively described skin structure in the disease region was formed for each image. To reduce the feature space redundancy, cross-correlation between the given features was evaluated. As a result, parameters with the Pearson correlation coefficient $|r| > 0.9$ were excluded from further analysis. To select features sensitive to a change in skin condition during the dermatitis formation, the Pearson correlation coefficients were calculated between the texture property values and experimental day number (days 1 to 6). Features were ranked by the modulus of correlation coefficient. The principal component analysis (PCA) method was further used to illustrate the trends in texture properties. The first two principal components were used to describe data variation using the PCA results. Finally, correlation coefficients between two principal components and PASI were calculated to evaluate the sensitivity of texture properties to dermatitis development.

Histological examination

In order to verify the formation of psoriasis-like dermatitis on the 6th experimental day, skin biopsy samples were taken from experimental regions (animals with dermatitis model) and control regions (normal animals) for further histological analysis. When taking the biopsy samples, the animals were anesthetized with a mixture of Zoletil (Virbac, France) and Xylanit (Nita-Pharm, Russia). After excision, the skin biopsy samples were fixed using 10 % formalin solution and then histological processing, paraffin impregnation and microsectioning stages were performed. The obtained sections were stained with hematoxylin and eosine, and imaged using the Olympus IX73 microscope (Olympus, Japan).

Results and discussion

The study was performed in a psoriasis-like skin inflammation model in rats. Psoriasis is a multifactorial skin disease characterized by high populational frequency which is 2−3 % on average from the total global population, and reaches 11 % [24] in some regions. Many aspects of the pathogenesis of psoriasis remain poorly understood, however, its modern understanding indicates a violation of the immune regulation of T-helper 17 cells as the cause of hyperproliferation and metabolic activation of epidermal cells, leading to appearance of red spots with silver scales on the skin [9,25]. The pathogenesis of the disease is manifested by thickening of the epidermis (acanthosis), hyperkeratosis and pronounced inflammatory cellular infiltration [26]. In addition, the psoriatic skin is characterized by excessive vascularization and increase in the number of tortuous capillaries in the upper dermis [9,26].

The selection of a methodology for forming a model of psoriasis-like dermatitis was carried out on the basis of literature data, focusing on simplicity, reproducibility and feasibility. An imiquimod-induced dermatitis model was chosen [22] which suggests the use of an immunomodulating cream with 5 % of imiquimod as a pathology inducer. The protocol of the model formation involves topical application of such cream once a day during at least 5 days. According to the literature, imiquimod is a ligand of toll-like receptors (TLR7 and TLR8) that activate production of

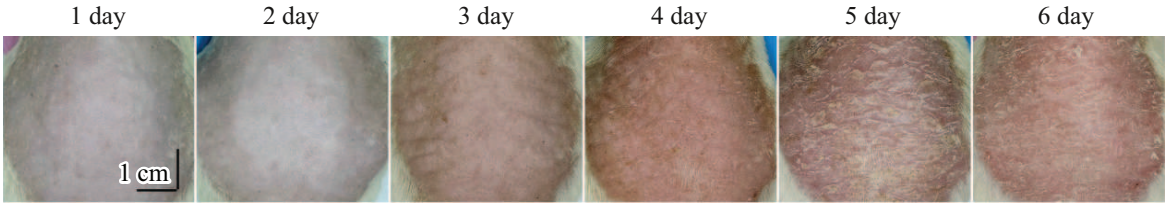


Figure 1. Typical photographs of a rat skin showing the development of a psoriasis-like dermatitis model (days 1 to 6).

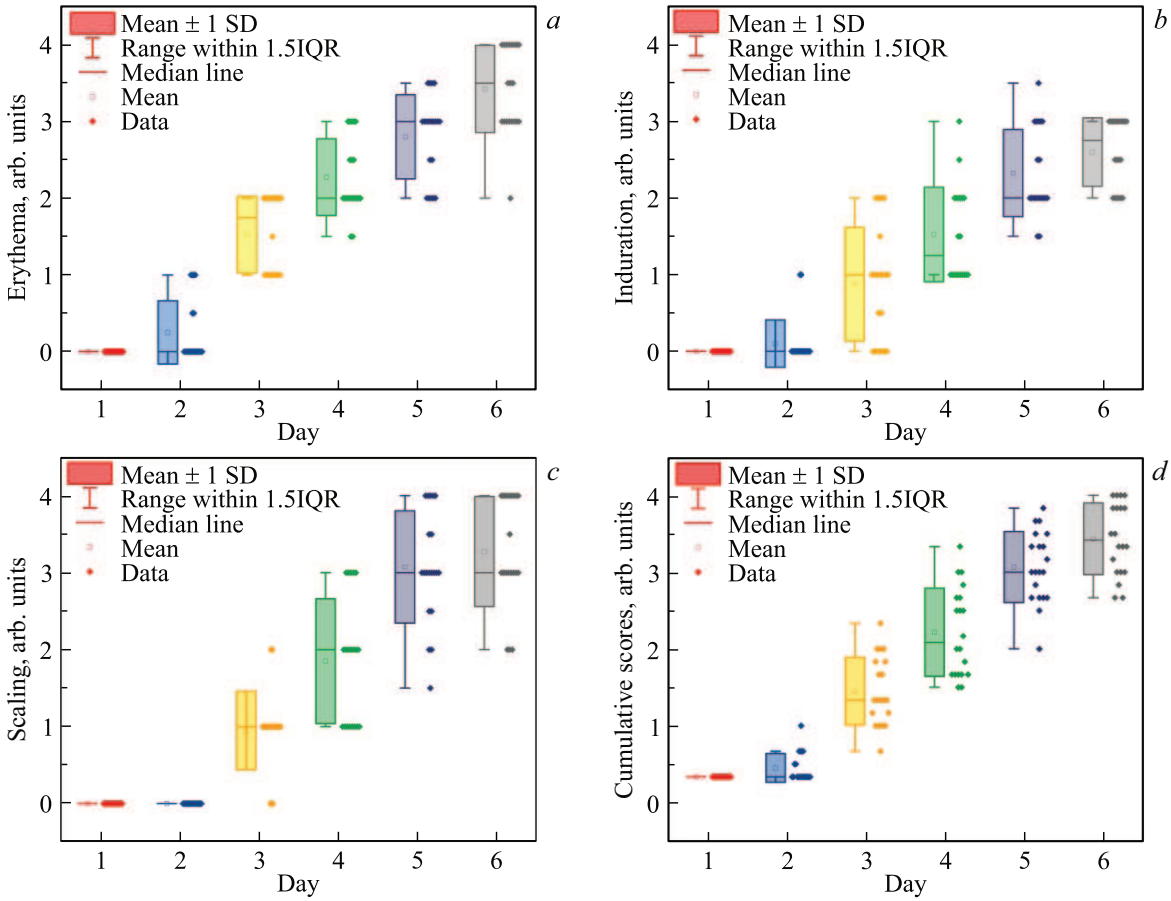


Figure 2. Visual assessment of the severity of clinical manifestations using PASI scoring system: erythema (*a*), induration (*b*), scaling (*c*) and cumulative scores (*d*) for the experimental skin area. Evaluation was performed on a scale of 0 to 4, where 0 is no manifestation, 1 is minor manifestation, 2 is moderate manifestation, 3 is pronounced manifestation, 4 is severe manifestation.

proinflammatory cytokines and chemokines, which leads to immune response cell inflow to the imiquimod application site [27]. The use of this medication leads to an increase in epidermis thickness due to keratinocyte hyperproliferation and to perivascular inflammatory cell infiltration.

In our study, the model formation took 5 days, observation time was 6 days. Daily photographs and the results of visual assessment using PASI are shown in Figures 1 and 2, respectively. It is important to note that the level of consistency between the two experts in assessing the PASI scores was high. Thus, weighted Cohen's Kappa coefficients for evaluating the erythema, scaling, induration and cumulative scores were 0.96, 0.97, 0.95 and 0.98, respectively.

Observation of animals during 6 days after the start of psoriasis-like dermatitis model formation showed the progression of disease accompanied by an escalation of the inflammatory process and an increase in severity of clinical signs (erythema, scaling and induration) (Figures 1 and 2). Histological analysis of skin biopsy samples taken from experimental animals on day 6 (Figure 3) confirmed that the psoriasis-like model had been successfully formed. Thus, microphotographs of rat's skin samples clearly showed epidermis thickening and pronounced inflammatory infiltration, causing the observed scaling and induration.

To confirm the results of visual assessment, texture analysis of the digital photographs was performed using custom-tailored software in Python and provided quan-

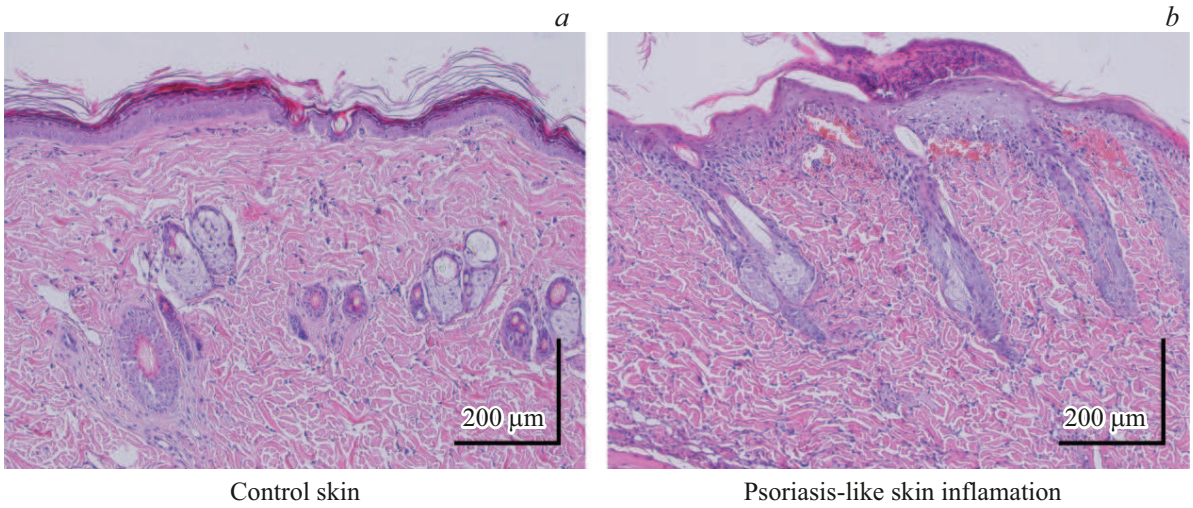


Figure 3. Typical microphotographs of histological skin biopsy specimens collected from rats in the experimental and control groups.

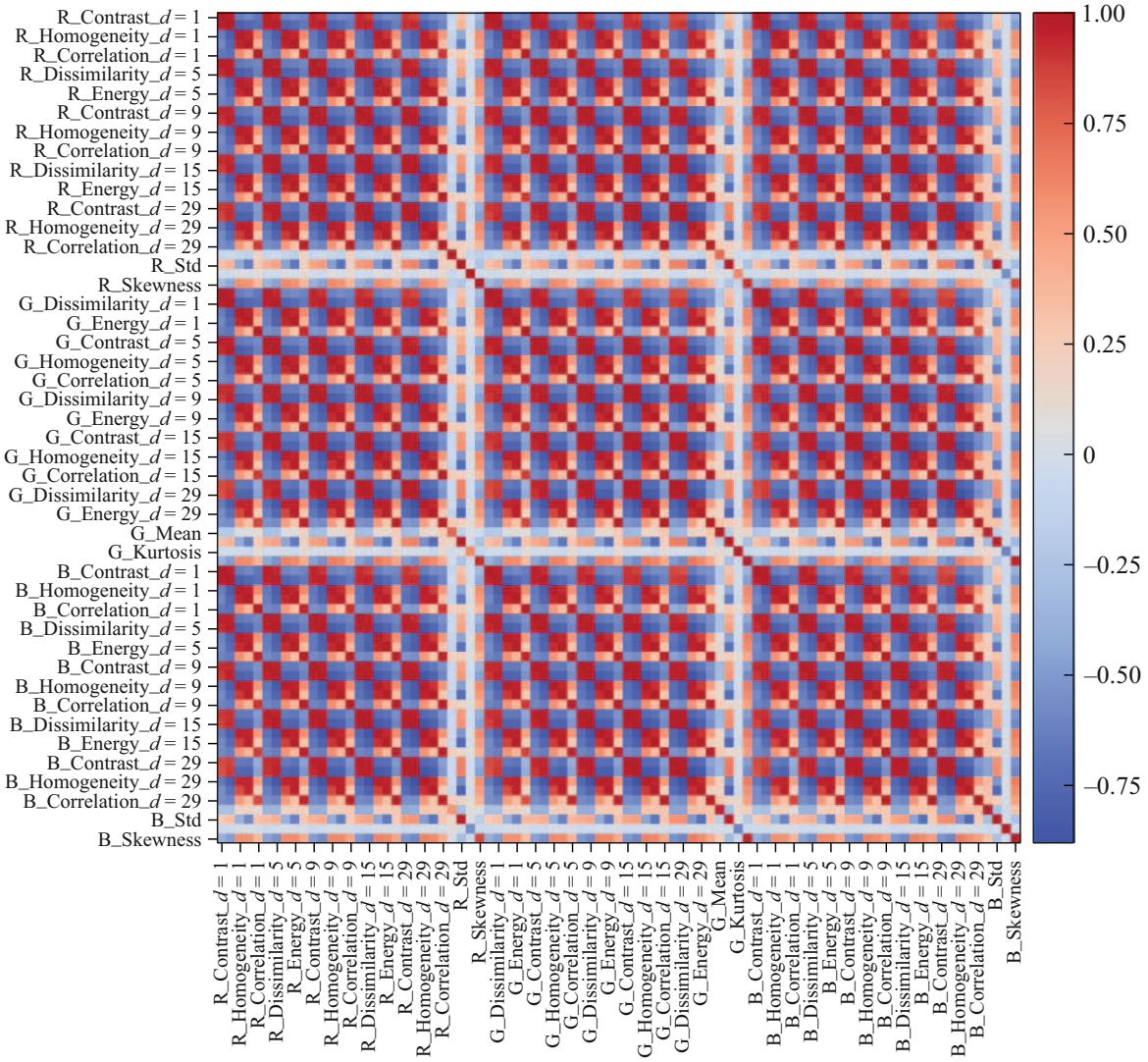


Figure 4. Cross-correlation coefficient matrix of texture features calculated using digital RGB images of the psoriasis-like skin disease. Designations: R, G, B — color channels; Contrast, Dissimilarity, Homogeneity, Energy, Correlation — features calculated using the gray level co-occurrence matrix (GLCM); d — pixel spacing ($d = 1, 5, 9, 15, 29$) used for GLCM calculation; Mean, Std, Kurtosis, Skewness — first-order statistical parameters in the region of interest.

titative evaluation of skin structure changes over time. Figure 4 shows the correlation matrix of all calculated texture features ($n = 87$) obtained using digital RGB images of the dermatitis lesion. Note that a significant part of parameters forms groups with very high cross-correlation indicating substantial redundancy of the initial feature space. The correlation matrix analysis was used to select independent texture features. Parameters with a high cross-correlation (modulus of the Pearson correlation coefficient $|r| > 0.9$) were excluded from further analysis. Then the Pearson correlation coefficients between each feature and experimental day number were calculated (days 1 to 6 after the start of psoriasis-like dermatitis generation). As a result, 6 most informative features sensitive to skin condition changes during dermatitis progression (Figure 5) were selected from 87 initial texture parameters.

Figure 5 shows the Pearson correlation coefficients between the selected texture features and dermatitis progression day number. The most pronounced time dependency is demonstrated, in particular, by G_Dissimilarity_$d = 29$ and G_Std, as well as by blue channel parameters: B_Homogeneity_$d = 29$, B_Correlation_$d = 29$, B_Mean and B_Skewness, indicating high sensitivity of these texture features and brightness distribution in the green and blue channels to structural changes in skin. The selected features reflect multifactorial changes in the structure and optical response of the skin during the development of dermatitis. The physical interpretation of the selected features is consistent with the morphology of the developing inflammatory lesion. Changes in parameters that reflect heterogeneity (for example, an increase in Std and Dissimilarity, and a decrease in homogeneity/correlation) correspond to appearance and progression of scaling and microrelief changes leading to alternation of areas with different brightness and local shadow. The features calculated with large d are more sensitive to large-scale structures (groups of scales), while small d predominantly reflect a fine-grained texture and appear to be less diagnostically relevant. Changes in the blue channel (for example, B_Mean, B_Skewness) are associated with an increase in light absorption in skin surface layers as the erythema develops, which alters the brightness distribution in ROI.

To visually assess the behavior of textural features in principal component coordinates, distribution diagrams of the first and second principal components (PC1 and PC2) over the days of the experiment were constructed (Figure 6). PC1 explains 69.5 % of the total feature dispersion and thus reflects the main direction of skin texture changes during psoriasis-like dermatitis progression. PC2, which accounts for 17.1 % of dispersion, characterizes additional less pronounced texture variations. Distributions of PC2 values by days partially overlap, however, also reflect time changes in the skin structure and intra-group variability. PC1 values demonstrate a pronounced monotonic downward trend from experimental days 1 to 6: at early stages (days 1 to 2), median PC1 values are positive and significantly higher, while by days 4 to 6, the distribution moves into the

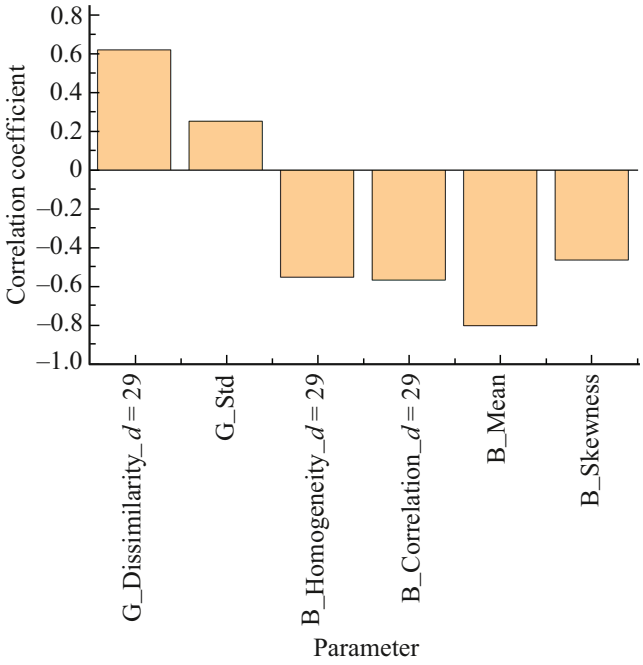


Figure 5. Pearson correlation coefficients between the selected texture features calculated from digital RGB images and the dermatitis progression day number (days 1 to 6). Features remaining after exclusion of parameters with high cross-correlation are shown.

negative values. This indicates a successive change of a set of texture parameters as the inflammatory process in skin progresses.

A comparison of PASI score behavior (Figure 2) with changes of principal components of texture features (Figure 6) shows a qualitatively similar dynamics: an increase in the partial and cumulative PASI scores is accompanied by a decrease in PC1 values, which explain the main portion of variance in the texture features. At early stages (days 1−2), high PC1 values correspond to the lowest PASI scores, while at late stages (days 5−6), the highest cumulative PASI values are observed at the background of the lowest PC1 values. This indicates that the first principal component calculated from the texture parameters reflects the severity of dermatitis consistent with the clinical assessment of the PASI index.

To quantify the consistency of textural analysis with the clinical assessment of dermatitis severity, the dependence of PC1 on the cumulative PASI score was considered and the Pearson correlation coefficients were calculated (Figure 7). The scatterplot (Figure 7, *a*) demonstrates a pronounced reduction of PC1 values with the growth of the cumulative PASI scores: a point cloud is elongated along the descending approximating straight line. Color coding by days of observation (days 1 to 6) shows that early stages correspond to high PC1 values and minimum PASI scores, while late stages correspond to low PC1 values and maximum PASI scores. The correlation matrix (Figure 7, *b*) confirms the existence of a strong correlation between PC1

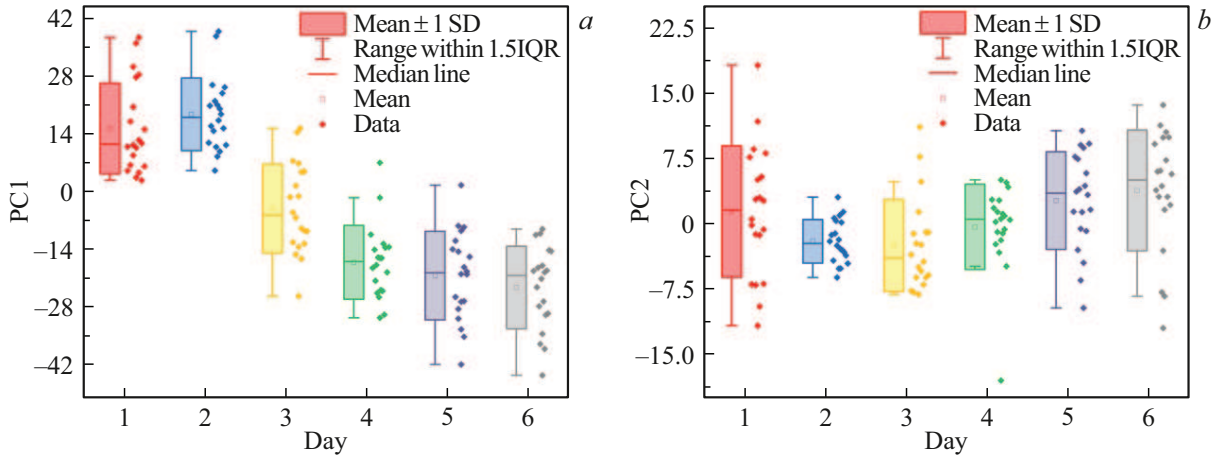


Figure 6. Distribution of PC1 (*a*) and PC2 (*b*) values (explaining 69.5 % and 17.1 % of the general variance, respectively) by psoriasis-like dermatitis progression days calculated from the texture analysis of digital RGB images.

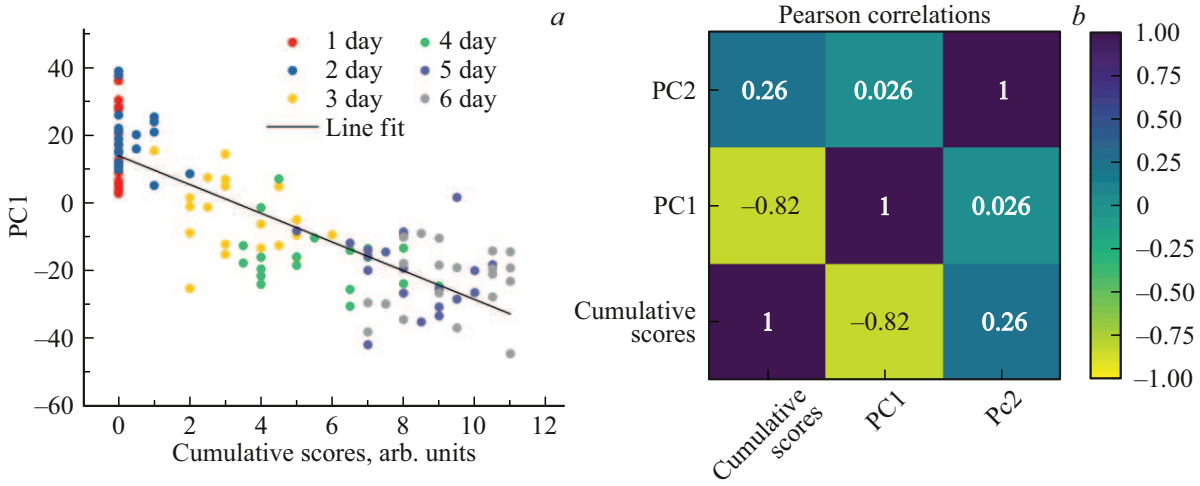


Figure 7. Correlation between the principal components of texture features and cumulative scores for PASI in the psoriasis-like skin lesion: *a* — PC1 scatterplot (69.5 % of the total dispersion) depending on the cumulative PASI score, observation days are marked with color (days 1 to6), solid line — linear approximation; *b* — matrix of the Pearson correlations between the cumulative PASI score, PC1 and PC2.

and the cumulative PASI index ($r = -0.82$, $p < 0.0001$). PC2, on the contrary, demonstrates a moderate positive correlation with PASI ($r = 0.26$, $p = 0.004$) and is almost unrelated to PC1 ($r = 0.026$, $p = 0.77$). This indicates that PC1 reflects the main direction of variations in textural features associated with the severity of dermatitis, while PC2 describes additional individual characteristics of the skin structure.

Conclusion

This study used an imiquimod-induced psoriasis-like dermatitis model in laboratory rats to demonstrate the possibility of quantifying the severity of clinical manifestations of dermatosis based on texture analysis of digital RGB images of the skin. The selected six texture features appeared to be sensitive to the inflammatory process progression in the skin and showed a good consistency with the change in cumulative clinical PASI score ($r = -0.82$), suggesting that the proposed approach is suitable for improving the objectivity of visual assessment of the psoriasis severity. The texture feature-based approach can be adapted to other inflammatory dermatoses, however, each nosological type requires individual validation and verification of feature robustness to variation in image acquisition conditions and clinical variability conditions.

In our work, the application of the principal component method to a set of informative texture features allowed us to obtain an integral index that changes monotonously with the development of the pathological process. The findings show good prospects of integration of digital clinical image analysis with modern optical imaging methods into a single multiparameter skin monitoring system suitable for standardized assessment of therapeutic efficacy of new

dermatological medications both in pre-clinical and clinical trials.

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Compliance with ethical standards

All studies involving laboratory animals were performed in accordance with the Declaration of Helsinki on Animal Use in Research and in full compliance with the research protocol approved by SSMU Ethics Committee (protocol № 8 as of 04.02.2025).

Conflict of interest

The authors declare no conflict of interest.

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