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Objectification of the Assessment of Individual Skin Erythema Characteristics to Determine the Safe Dose of UV Impact on the Human Body.

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ABSTRACT

The energy of the solar radiation light plays an important role in the energy metabolism of the human body. It is an ascertained fact that light energy influences the human organism positively, which is used to correct the condition of a human organism. In this paper we propose a method based on a phased study of individual characteristics of the skin, consisting of skin phototype classification; creation of a mathematical model that describes individual properties of skin erythema; experimental study of a selected area of skin and obtainment of the model of human population that suffers from health problems caused by light starvation (e.g., people working in mining). This leads to the need for rehabilitation measures, intended to compensate for energy losses. Ultraviolet part of the light radiation energy spectrum has a special place in its structure, parameters values (grade level); prognostication of the radiation characteristics based on an analysis of the dynamics of the model parameters and initial state of the biological object. To implement this method we propose using a biotechnical system that provides implementation steps of the proposed method to assessing skin characteristics; storing bioobject personal data and radiation history; correcting procedure of controlled and metered exposure; assessing and monitoring human organism and environment parameters during radiation; notifying users on a hazardous situation related to bioobject.

Keywords: ultraviolet, solar failure, skin, biotechnical system, protection.

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INTRODUCTION

The main task of every biological creature (including human being) is a continuous exchange of energy, substances and information with the environment and functional systems of the organisms. The energy of solar light radiation plays an important role in energy metabolism.

It is an ascertained fact that light energy influences the human organism and exact functional systems positively. Part of the human population living in regions with a relatively small amount of light energy suffers from health problems caused by light starvation. Similar problems arise in professional societies, which activity is accompanied by light deficiency (miners, underground workers, etc.). This leads to the need for rehabilitation measures intended to compensate for light and energetics losses [1, 2].

The ultraviolet part of spectrum occupies a special place in the structure of light radiation energy, which influences the human body. Both positive and negative aspects of the impact of UV exposure are studied and known. The modern medicine makes extensive use of artificial ultraviolet radiation for correction of individual organs and tissues of a human body.

It should be mentioned that an individual variation in the body response to UV exposure exists, and in some cases, the use of ultraviolet radiation is contraindicated. This necessitates the development of methods to determine the safe dose of ultraviolet radiation based on the assessment of personal characteristics of an organism. The analysis showed that the estimating methods based on expert assessment of changes in color characteristics of erythema are subjective and not accurate. It leads to the necessity of creating a method and equipment based on an evaluation of objective measures, which are to ensure the safe (metered and controlled) UV impact on human body [3].

Human (belonging to any bioobject) skin is an object of light exposure, which is carried out in the infrared spectrum (760-2000) nm and the visible spectrum (400-700) nm and ultraviolet (UV) light spectrum (315-380) nm, type A.

It is stated that the infrared and visible spectrum radiation does not cause significant residual changes of the skin and has different, mainly positive, effects on the organism of a bioobject. UV radiation has a strong influence on the skin and inside the body. This influence can be positive or negative depending on dose [4, 5].

The negative influence of the UV radiation is associated with skin irritation and/or its various degree burn, which can lead to various diseases (including oncologic).

It should be mentioned that the dose, which does not cause negative reaction, is individual and depends on many factors (e.g., skin phototype). The analysis of these factors with the help of modern mathematical procedures could allow to establish objective methods of assessing the state of skin and the body's biological object, making it possible to avoid receiving a dose of UV radiation above the allowable maximum [6-9].

It is known that erythema occurs during the UV radiation of skin. Its color characteristics depend on the radiation dose and can become a source of information for adequacy of the skin state assessment. However, the expert method by Gorbachev-Duckfield based on such evaluation is subjective and relies on the color sensations of an expert, his experience and intuition. This empirical approach inevitably leads to mistakes and blunders in the evaluation, the price for which is the human health.

For objectification of the assessment of skin erythema changes under UV radiation impact, we propose to construct a mathematical model, which could relate the impacts on biological object and its reaction to the impact [10, 11, 12].

MATERIAL AND METHODS

In general, the impact of the light radiation energy on human body may be represented as a pattern. Fig.1 shows its structure.

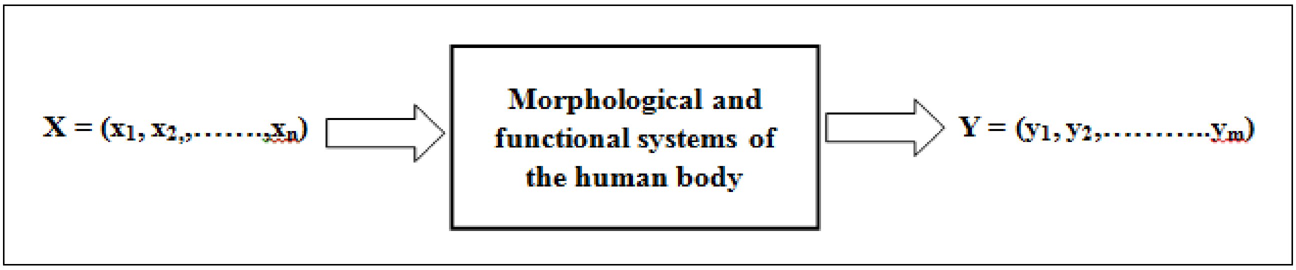

Figure 1: Generalized model of the light effect on human body.

Where: $X = (x_1, x_2, \dots, x_n)$ – vector of the spectral component parameters of the light radiation (independent variables); $Y = (y_1, y_2, \dots, y_m)$ – vector of evaluation parameters of reaction of a human body functional system to the light radiation (dependent variables).

In case of stationarity and ergodicity of these processes, a multiple regression model of the following form in general can represent the dependence of each parameter y_m of the plurality of Y on a set of independent variables X:

Non-linear:

$$y_i = \beta_o + \beta_1 x_{i1} + \dots + \beta_k x_{ik} + \varepsilon_i, \quad i = 1, \dots, n, \qquad (1)$$

(the second index of x refers to the number of factors and the first – to the number of observation). It is also assumed that ε_i – uncorrelated random variables.

Linear:

$$y_i = A + bx_i + \varepsilon_I \qquad (2)$$

Determining the type of model is associated with the proposed form of the dependence of the selected parameter estimates from a set of independent variables X. However, when using multiple regression analysis apparatus, such a choice is quite conventional.

A part of this work involves the construction of a mathematical model relating the dependent variable such as the assessment of the color characteristics of erythema – S and the independent variable such as D – Dose ultraviolet radiation in the range of (280-320) nm.

The reaction of a given biological system on disturbance can be represented by an S-shaped curve (Fig.2) where it is proposed to distinguish three zones:

Zone 1 – subthreshold values of radiation dose (D_0), where no significant changes in the values of erythema characteristics assessment are observed (S).

Zone 2 – admissible values of radiation dose (Dmin, Dmax), where there is a directly proportional dependence of the values of erythema characteristics assessment (S) on the radiation dose (D).

Zone 3 – invalid values of radiation dose (≥ Dmax), entering which the values of erythema characteristics assessment (S) reach its maximum and do not change with increasing dose (D).

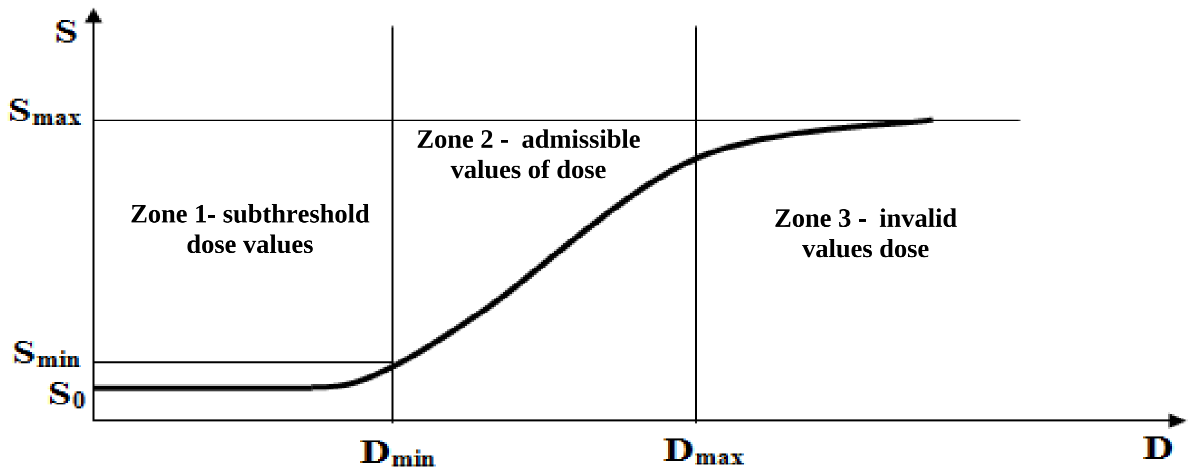

Figure 2: Theoretical dependence of values of the erythema characteristics assessment (S) on the radiation dose (D).

Initially – before radiation (S_0), the threshold (S_{min}) and the maximum (S_{max}) values of erythema characteristic assessment are individual. Having the information on the individual properties of erythema allows to [13]:

- take into account erythema initial state (S_0) in zone 1 (e.g., consider a dose, which was received in previous radiation sessions);
- minimize the use of subthreshold dose values ($\leq S_{min}$) in zone 1;
- provide light impact on the bioobject skin in the area directly proportional to the values of erythema characteristics assessment (S) on the radiation dose (D (Zone 2);
- predict the moment of reaching the zone 3, i.e. the maximum value of the erythema characteristics assessment ($\geq S_{max}$), thus reducing the likelihood of skin damaging dose.

DISCUSSION AND RESULTS

Light radiation dose (D, $(J*s)/cm^2$) is generated at a change of independent variables, the radiation intensity (E, J/cm^2) and exposure time (T, sec), and is determined by the expression:

$$D = E * T \quad (3)$$

For the evaluation of skin erythema characteristics (S), as the dependent variable, it is proposed to use the values of the spectral power density of light flux reflected from skin in the red spectral region (600-700nm), determined in accordance with the expression:

$$W_k(\omega) = \lim_{T \to \infty} X_{kT}(\omega)^2 / T \quad (4)$$

$X_{kT}(\omega)$ – *k*-th realization of the measured spectrum having a frequency ω and recorded at a time interval *T*.

It is proposed to build a regressive model that belongs to Zone 2 and links the intensity of radiation (E, J/cm^2) and the exposure time (T, c) with the evaluation of skin erythema characteristics (S). Response surface *S = F(E,T)* is approximated by the view plane (Fig.3), which is based on individual data obtained experimentally.

$$S = a_1E + a_2T + S_0 \quad (5)$$

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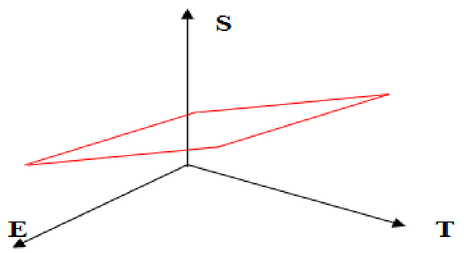

Figure 3: The theoretical model of response surface based S = F (E, T), built for zone 2.

The resulting analytical description of the individual response surface allows to monitor the status of skin erythema according to the evaluation value (S) and to predict the exposure time (T) (for a given value of the intensity of light exposure (E)), or, contrariwise, predict the intensity value (E) (for a given exposure time (T)).

It can be particularly important to get the opportunity to predict the moment of reaching the maximum value of radiation dose (D_{max}). Considering the cumulative nature of the formation of erythema, the initial (before exposure) value of its estimation (S_0) can be taken into account in the model in case of multiple and separated in time impact [14-15].

While implementing the method of controlled light exposure on human skin, it is suggested to use the principles of biotechnical system (BTS) creation, which unites biological object (skin and functional systems of the body) and hardware into a single control loop to implement a given objective function. In this task, the target function is metered and controlled UV radiation of human skin, which is the main biological object. Technical means ensure the formation and interaction of processes, intended to adapt the impact parameters to the characteristics and the current state of erythema. For the adaptation, the sequence of BTS functioning phases is used. The phases lead the following interacting processes (fig. 4):

Classification of skin phototype;

- obtainment of the experimental information to construct a mathematical model of the individual properties of skin erythema (learning process);
- predicting impact time and intensity to ensure adequate impact (considering minimal damaging effect on the selected skin area);
- monitoring the condition of the human body major functional systems during radiation as an additional factor of light exposure safety;
- control of the environment in order to create favorable conditions for the existence of a human being during the implementation of the light exposure.
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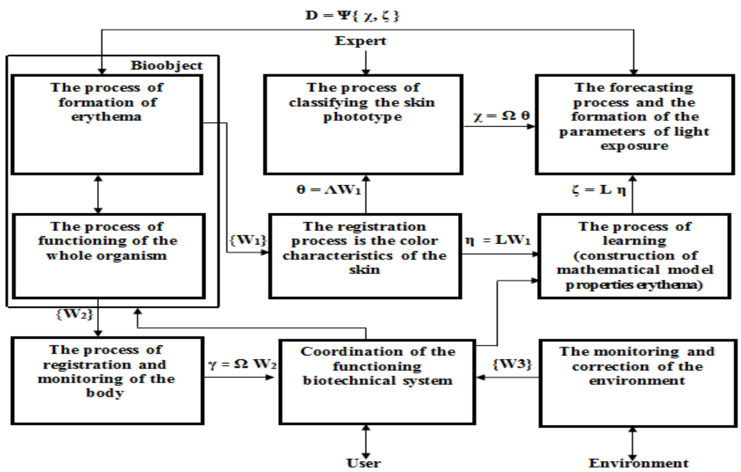

Figure 4: Structure interaction processes in the functioning of the biotechnical system controlled light exposure on human skin.

Where:

W_1 – parameter vector of erythema; W_2 – parameter vector state of the organism; W_3 – vector of parameters of the environment;

θ – the result of measuring the condition of erythema; γ – the result of estimating the parameters of the state of the body; η – the result of measuring changes in the condition of erythema of the skin; ζ – the result of estimating the parameters of the mathematical model of the condition of erythema; χ – skin phototype classification result;

Ω, Γ, Λ, L, Ψ – conversion operators;

D – the current parameter vector of the light exposure.

CONCLUSION

The developed method and biotechnical system improve safety of the UV radiation of human skin with use of the following processes:

- Classification of the bioobject skin phototype.
- Construction of mathematical models describing the individual properties of the bioobject skin erythema.
- Predicting the values of the independent variables (E, T) before the next session of UV radiation based on the analysis of the dynamics of the model parameters and estimation of the initial condition of the bioobject erythema (S_0).
- Implementation of correct mathematical and metrological procedures of monitored and metered UV radiation.
- Control and assessment of the bioobject functional systems during the procedure of UV radiation.
- Control and correction of the environment during the UV exposure procedure.

The developed method and the BTS can be improved by attracting additional methodologies for assessing the effect of light exposure and its impact on the human body, including biochemical, biophysical and physiological levels, which are involved in the response to UV exposure.

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