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OVERVIEW OF SKIN DIAGNOSTIC TECHNIQUES BASED ON MULTILAYER SKIN MODELS AND SPECTROPHOTOMETRICS

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Abstract. *Today, spectrophotometrics is a promising tool for non-invasive examination of the optical properties of human skin. The spectrum obtained during the study is carefully analysed by models developed by many scientists. Developed multilayer models are designed to reflect the most faithful processes occurring in the skin, its layers and essential elements. Many skin diseases are diagnosed: vitiligo, hemangios, skin birthmarks, melanoma. The article provides an overview of interesting solutions using spectrophotometrics in the process of diagnosing skin diseases.*

Keywords: multi-layered skin models, skin disease diagnosis, spectrophotometrics, spectrum

PRZEGLĄD TECHNIK DIAGNOSTYKI SKÓRY W OPARCIU O MODELE WIELOWARSTWOWE SKÓRY I SPEKTROFOTOMETRIĘ

Streszczenie. *Obecnie spektrofotometria jest obiecującym narzędziem do nieinwazyjnego badania właściwości optycznych ludzkiej skóry. Otrzymane podczas badania widma poddawane są wnikliwej analizie dzięki opracowanym przez wielu naukowców modeli. Opracowane modele wielowarstwowe mają na celu oddać najwierniej procesy zachodzące w skórze, jej warstwy i istotne elementy. Diagnozowanych jest wiele chorób skóry: bielactwo, naczyniaki, znamiona skórne, czerniak. Artykuł przedstawia przegląd ciekawych rozwiązań z użyciem spektrofotometrii w procesie diagnostyki chorób skóry.*

Słowa kluczowe: modele wielowarstwowe skóry, diagnostyka chorób skóry, spektrofotometria, widma

Introduction

Human skin is an important organ of the human body that performs many important functions in human life processes. Due to the great interest of researchers, all its properties are increasingly known. In the diagnosis of skin diseases, methods using phenomena associated with the influence of electromagnetic radiation have been widely used. Human skin consists of the main three layers in which we can distinguish absorption, refraction and scattering of light. Numerous studies [16, 24, 40] have shown that the skin contains various chromophores that absorb light in a wide range of waves, from ultraviolet to near-infrared.

Scientists have been working for many years on models of the interaction of light rays with individual skin layers [32]. Attention is paid to the type of tissue and the elements knowing in the skin, which show different properties. In [3] a model of the effects of radiation during the skin test was presented. It includes melanin and hemoglobin absorption, Mie and Rayleigh scattering, surface and subsurgial scattering, radiation reflection from subcutaneous tissue. The epidermis is the first layer of the skin that partially reflects light.

The direction of light is changed by the presence of cell membranes and organelles with different refection factors. Light in the epidermis is absorbed by melanin and dissipated further [3] Some radiation is dispersed by melanosomes. On the other hand Mie's dispersion occurs in a larger fiber of collagen and elastin, and can be directed towards a deeper layer. Subcutaneous tissue is mainly built up by bright fat cells that will reflect light. An example of the course of light rays through different layers of skin is marked in yellow in Figure 2B.

Studies of the optical properties of human skin are currently carried out due to spectrophotometrics. Based on spectrophotometric spectrum analysis [8], the transport of light through tissues for each layer of human skin can be described and its optical properties can be represented using mathematical models. Transmittance, absorption, dispersion and refinement factors, concentration of selected elements building it are also determined. For different wavelengths, maximum absorption is absorption. Many scientists are involved in determining absorption coefficients for elements that build human skin [4, 13, 19]. Figure 1 takes into account the absorption coefficient for oxyhemoglobin, water, deoxyhemoglobin and melanin. Human skin is mainly made of these elements, so it is worth paying attention to the shapes of their absorption spectrum. It is on the basis of spectre and developed models that diagnostic decisions are made [15, 17]. To receive a full diagnosis, it is necessary to know the anatomical structure of human skin, the processes of the influence of ultraviolet radiation, visible light and near infrared in each layer of the skin. It is important to have knowledge of the optical properties of the elements that build it.

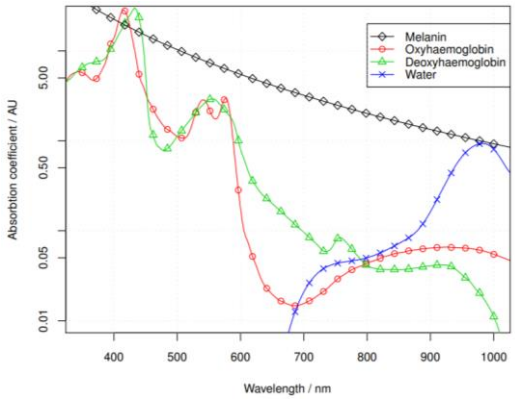

Fig. 1. Absorption factors of hemoglobin (oxyhemoglobin and deoxyhmoglobin), water, melanin [33]

1. Multilayer skin models

Scientists try to interpret optical phenomena in different ways in the skin. Many works are being created to show the ever-new properties of the elements in the skin. In addition to the number of important and different layers, models provide a lot of other information. These include melanin content, melanin absorption of useful wavelength, blood absorption from oxidized and oxidized hemoglobin [13, 17], blood volume fraction, oxygen saturation. The optical properties of a particular layer can be represented by a set of numbers of developed models. These include optical depth, single albedo dispersion, standardized volume dispersion function. It all depends on the wavelength and the type of structure.

1.1. Models 1, 2, 3 layer

Single, double and three-layer models are based on less complex assumptions about the optical properties of skin-building elements. A small number of variables are needed to use them to fully simulate models. They are useful in determining concentration, absorption coefficients of skin elements. On the other hand, they describe more accurately the optical interactions taking place in human skin. In [20] a model of two-layer leather is used, its layers are different in composition and optical properties. The top layer is an epidermis with a thickness of 50–150 μm, the next layer is dermis, which in optical terms is considered an

infinitely thick element. The volumetric absorption coefficients of epidermis and dermis, the volumetric content of melanin in the epidermis and the effect of the change in light absorption by blood vessels [2, 40] have been determined.

Figure 2A shows a two-layer leather model based on 3 layers of skin. A layer (s.i.) is included, which has properties evenly distributed throughout the layer. The components of the diffuse spectrum reflections contain information on different depths of penetration of light rays through the skin [15].

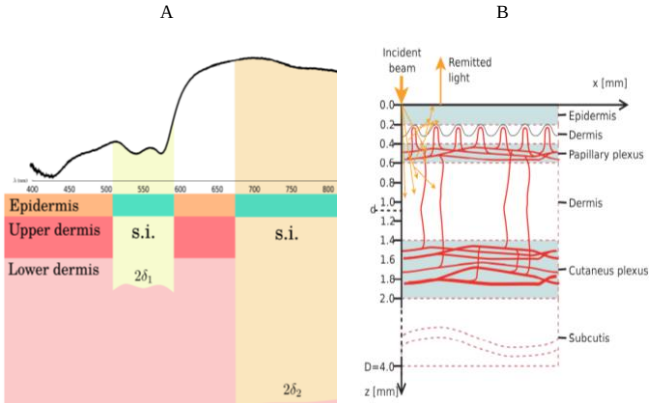

Fig. 2. Leather models created: A) double layer [4] and B)six-layer [34]

The rays of light with a shorter wavelength penetrate more superficially due to the high absorption of hemoglobin and melanin [21, 25, 38]. The author of the model determined the average depths of optical penetration through the dermis.

1.2. Models 4, 5, 6, 9 layer

More complex models contain four layers and more accurately describe the processes associated with radiation in the skin. They allow you to know the optical properties of the elements of the skin. However, they have their disadvantages. The known data are not accurate, many approxims and assumptions. In addition, they introduce many complex variables into the simulation giving errors. Many of their assumptions are based on complex simplifications and not yet fully studied and described phenomena.

The spectral spectrum is simulated by a combination of multiple methods. The Monte Carlo method was used in a four-layer model to analyze diffusion [4]. In this case, the dermis was divided into two layers - papillary and reticular skin. The authors of the paper [31] proposed using a five-layer leather model to simulate the size of the falling beam and the reflection and refraction of light at the contact between layers. In addition, a layer of superficial skin is separated from the dermis. They have different optical properties resulting from the presence of a large number of small blood vessels in it. Fig. 2B presents a five-layer model of human skin. Based on available literature [5, 12, 36], researchers are developing mathematical models. Numerous optical parameters of tissues have been determined, the most commonly mentioned are: absorption coefficient (μα), dispersion factor (μs), reoffer coefficient of the center (n), sample thickness (d) in centimeters are shown in table 1.

Table 1. Optical parameters of skin layers in a five-layer model for selected wavelengths [30]

Layer	λ [nm]	μα	μs	n	D
epidermis	337 633	32 4.3	165 107	1.5	0.01
I dermis	337 663	23 2.7	227 187	1.4	0.02
surface skin layer	337 633	40 3.3	246 192	1.4	0.02
II dermis	337 633	23 2.7	227 187	1.4	0.09
deep-seamed skin layer	337 633	46 3.4	253 194	1.4	0.06

Many scientists build skin models consisting of more layers of six, seven, or even nine. The six-layer mcml simulation leather model is used in many works [6, 28, 34]. The parameters of the model consist of values that are determined by the concentration of the most important skin chromophores. The nine-layer model of skin tissue was developed in [22] for spectral simulation using the Monte Carlo method. The necessary parameters were output for each of the nine layers in the simulation. The parameters used in the conventional three-layer model have been modified on the basis of some histological findings on the skin and reported examples. It occurs here: the stratum corneum, the epidermis layer (which consists of a granular layer, spinosum and base layer, the dermis is divided into five layers, the last is subcutaneous tissue.

In the dermis, the blood vessels are not homogeneous and the saturation of hemoglobin with oxygen must be separated. The volume and composition of the elements of the liner may also vary. By adopting different optical and geometric parameter values in each of the nine layers, you can simulate the reflectance spectrum under different conditions.

2. Non-invasive diagnosis of skin diseases

Diagnosing pigmented skin lesions in general practice is difficult. For diagnosis there are many stages and types of skin lesions, they are also located in different places on the body. There are many important characteristics for them, e.g. the presence of skin melanin, displacement of blood with erythuoma, a different collagen structure.

2.1. Diagnosis of basic skin diseases

The most commonly diagnosed skin diseases diagnosed by spectrophotometrics are warts, vitiligo, thrombosis and hemangios [1]. Scientists study various abnormalities of the skin in selected regions of the skin. In [26] diagnostics of warts, vitiligo and hemangios were taken. Fig. 3A shows the original reflectivity spectrum for the nipple and control skin along with the designated reflectivity. Similar graphs were created for vitiligo-covered skin – Fig. 3B. The intensity of light reflected from the skin with vitiligo is higher than for normal skin. Vitiligo introduces melanin-free areas on the skin that achieve maximum reflectivity. The spectrum of the test area of the skin and control spectre shall be compared using statistical analysis to detect wavelength ranges, regions with significant differences [19].

Changes in the shape of the spectrum help to distinguish between healthy and affected tissue. [13] the healing process of burns was taken into interest. Areas of skin after burn and healthy skin were compared using spectrophotometrics. The color of the restored skin became more red in people exposed to the sun and in older people, the received spectrums were significantly different from each other. Also interesting is the topic [29] of the use of spectrophotometrics in the analysis of skin color arising from the healing process of burns.

Often spectrophotometrics is not a sufficient diagnostic tool. This diagnostic technique is combined with other tools. [27] a Doppler laser is used to assess oxidation and perfusion in the oral skin. Real-time optical parameters of the skin are also used for hyperspectral imaging to obtain volumetric fractions in the blood, oxygenation of melanin content and RGB image of the skin area under test [18]. Spectroscopic studies are also used in cancer research in cancer therapy [23, 37].

Scientists use spectrophotometrics in the diagnosis of skin melanoma. The study refers to the incidence of melanoma in the bright [10] and dark-skined populations of different ages and regions of the globe. The most commonly determined parameter then is the estimation of the content and density of melanin in the skin [9]. However, to correctly recognize the disease, it is necessary to prepare well for the examination.

In [35] attention was paid to how the result of the final diagnosis is influenced by the presence of dark hair on the skin.

Fig. 4 shows the variability in melanin density in ba-given tissue, taking into account the hairy and smooth area depending on the season. Neighborhoods more likely to come into contact with solar radiation as the hand have higher concentrations of melanin in its composition.

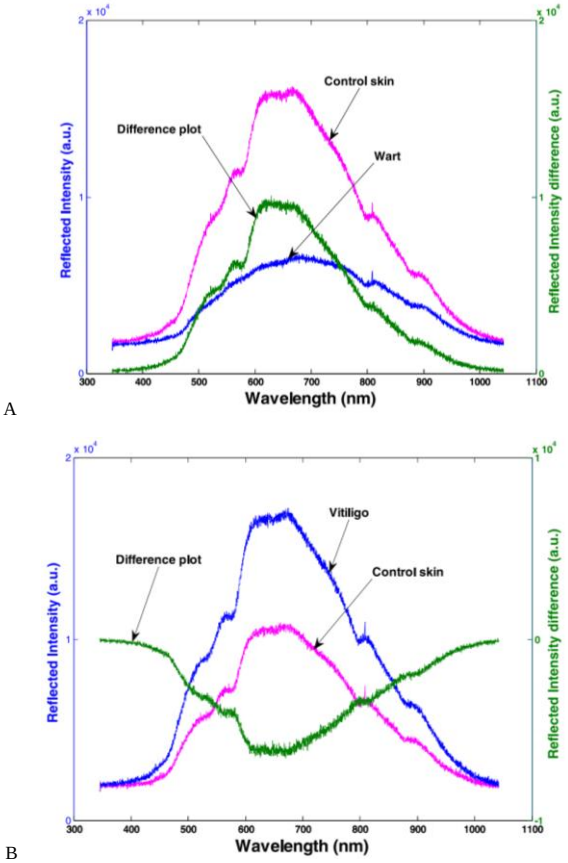

Fig. 3. Diffuse reflection spectrum and reflectivity factors for A) warts and normal skin, B) vitiligo and normal skin [26]

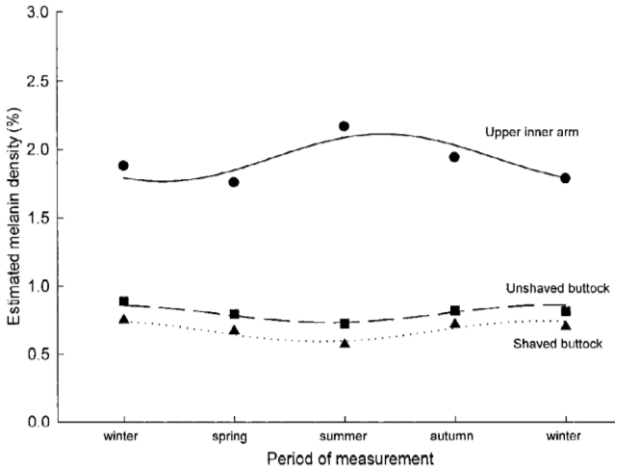

Fig. 4. Graph of melanin density changes in the upper inner arm, unshaved and shaved buttocks depending on the period of time [35]

2.2. SIAscopy

Spectrophotometric Intracutaneous Analysis (SIA) allows you to diagnose pigmented benign and malignant skin lesions. In addition, it analyzes the pigmentation of the skin with melanin, blood supply to the skin and its collagen structures [14, 39]. SIAscopy provides information about the thickness of the layers of the skin and the amount of hemoglobin, melanin and collagen in the stratum corneum and dermis.

The scans made inform about changes in the composition of the skin and ensure early detection of changes in the amount of dermal melanin. SIAscopy is equipped with a model of skin coloration, shows the relationship between the parameters that characterize the skin and its colors. Spectrum analysis, parameters determining the structure and optical properties of the skin allowed the model to be developed [15]. Melanin penetrates deep into the dermis in case of more malignant skin tumors.

SIAscope diagnoses benign lesion, malignant melanoma, keratosis and hemangioma. Fig. 5 is a set of images of replaced skin lesions [1]. They take into account the place on the patient's body and 6 characteristic resulting images. The resulting images include a dermatoscopic image, an image of the concentration of melanin in the epidermis and dermis layer, an image of hemoglobin and a picture of collagen concentrations in tissue. Images carry a lot of diagnostic information. The dark color in the image of total melanin indicates a large amount of it in the tissue. Collagen's grups are bright, and its deficiencies give darker areas in the image. However, the deficiencies of skin blood in the image suggest necrosis. Its growth on the periphery suggests the appearance of inflammation and vasodilation in the area of active tumor development [7].

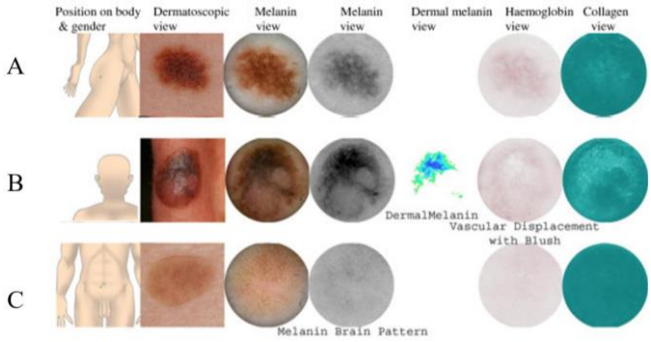

Fig. 5. Examples of images obtained from SIAscope with marked characteristics: A) mild change; B) malignant melanoma; C) seborrheic keratosis [11]

3. Conclusions

The use of skin models developed by many scientists helps to determine the presence or stage of cancer. The use of spectrophotometrics significantly reduces the use in clinics of invasive and painful biopsy for the patient. Non-invasive measurements of haemoglobin and bilirubin in the blood can be performed remotely. They do not require contact between the measuring instrument and the skin, they develop telemedicine. Human skin is a complex and organized part of the human body. Significantly different types of tissues, vessels and their function in each in layers. A closer understanding of its optical properties makes it possible to develop many diagnostic methods of its diseases.

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