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OPTICAL PROPERTY OF DERMIS AND EPIDERMIS LAYER

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ABSTRACT

Human skin comprises several distinct layers. Each layer is made of various components with a unique structure. To have a good insight into the overall optical behavior of the skin, we study the optical properties of the different layers. For all noninvasive optical process, accurate measurement of absorption of light as well as scattering in different tissue layers are major problems. More over the subcutaneous fat layer thickness, melanin concentration varies from individual to individual. Hence the outcome of optical measurement through tissue layers becomes erroneous due to the non-uniform properties of fat and other tissue. Here a mathematical modeling of absorption and scattering of light in various tissue layers is proposed to resolve such errors. Using this model the absorption and scattering of light in dermis and epidermis is measured.

Keywords: Dermis, Epidermis, Human Skin, Light Absorption, Light Scattering

I. INTRODUCTION

Skin is the outermost tissue of the body and the largest organ with a total area of 16000 cm2 and represents 8% of the body weight [1]. Skin has a multilayer structure and comprises of many components. Three main layers of skin are epidermis, dermis and subcutaneous tissue. Epidermis is the outermost layer of skin with an average thickness of 100µm [2], dermis is much thicker layer than epidermis (usually 1-4mm [2]) and consist of collagen and elastin fibre. The third layer is subcutaneous layer (from 4-9 mm thick [1]), found below the dermis and includes large amount of fat cells. Optical properties of these layers differ significantly depending on their physio-anatomical characteristics. For example, light scattering behaviour of cells and fibre depends on their size and shape where as light propagation through dermis and epidermis varies due to difference in structure, density and thickness. The skin optical properties not only vary across individuals but also differ among one depending on different body locations. It is therefore very important to derive a skin model that will consider most of the above parameters to deduce different optical properties. Measurement of these optical properties can help in diagnosis of several disease, therapeutic applications and surgery. Two major optical properties of skin are absorption and scattering. Around 5-7% of incident light is reflected [3] and the remaining light is either absorbed or scattered by the different constituents of skin layers. The radiation coming back from the skin is composed of reflected radiation and radiation scattered from epidermis and dermis, and is called remitted radiation. Fig.1 depicts the transmission of light through different layers of human skin.

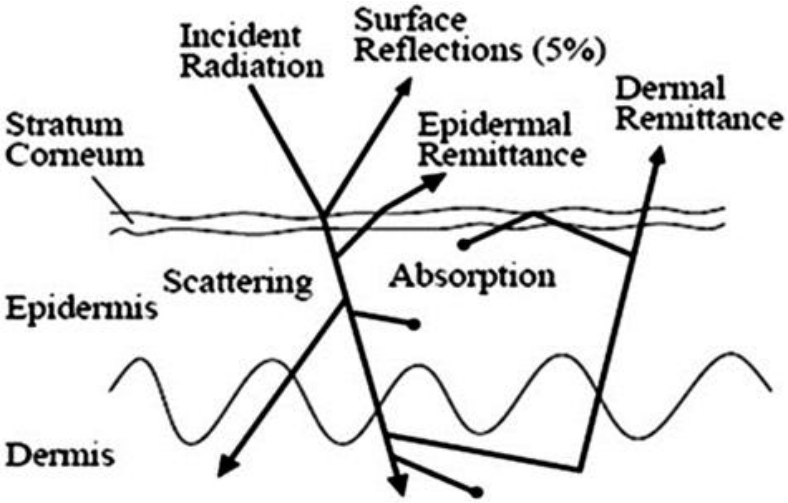

Fig 1 Optical Pathways in Skin

II. PROBLEM DEFINITION

It has been difficult to accurately determine the light absorption and scattering value in each of the skin layer distinctly. In this paper we have proposed a model to derive the absorption and scattering of light in both epidermis and dermis layer as a function of wavelength. Due to absorption of light there will be difference in the intensity of incident light and reflected light. So we can say that light scattering and absorption have a comparable influence on light intensity. At each layer we will compute the absorption and scattering distinctly. At the end we will compute the intensity of reflected light (The light coming out after being absorbed and scattered both in dermis and epidermis). So our final objective is to represent the emitted light intensity as a combination of both absorption and scattering coefficient of light.

III. PROPOSED MODEL

3.1 Mathematical Model

In this model we have obtained the absorption and scattering coefficient of epidermis and dermis based on the concentration of melanin and hemoglobin respectively. To identify the overall epidermal and dermal absorption we have also considered the absorption coefficient of individual absorbers in different layers. Similarly for scattering coefficient we have accounted the combined effect of Mie and Rayleigh scattering by different particles.The total absorption coefficient of both epidermis and dermis depends on minor baseline skin absorption [4]. This baseline skin absorption refers to melaninless epidermal and bloodless dermal absorption and is represented as :

$$\mu_{a\_skin}(\lambda) = 0.244 + 85.3 * e^{\frac{-(\lambda-154)}{66.2}} \quad (1)$$

where $\mu_{a_skin}$is the baseline skin absorption and λ is the light wavelength in units of nm. Here absorption coefficient is measured in units of cm^{-1}. Fig. 2 shows the graphical representation of baseline skin absorption coefficient with respect to wavelength. We have considered the wavelength in the range of 300-1100 nm. By putting the different values of wavelength in equation (1) we have obtained the graph in Fig. 2.

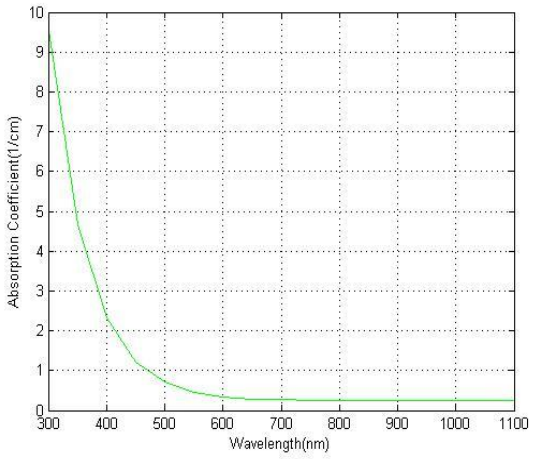

Fig 2: Absorption Coefficient of Skin Baseline

The absorption of epidermis is largely dominated by melanin absorption and varies to a great extent depending on the melanin concentration among individuals. Melanin is produced in melanosome, a special organelle. The approximated absorption coefficient of melanosome (μ_{a_mel}) is expressed as :

$$\mu_{a\_mel}(\lambda) = 6.66*10^{11}*\lambda^{-3.33} \quad (2)$$

and measured in units of cm^{-1}. Fig. 3 depicts the variation of melanin absorption coefficient with change in wavelength. The graph in Fig. 3 shows the different values of melanosome absorption coefficient due to change in wavelength in the range of 300-1100 nm. From Fig. 3 we can conclude that with increase in wavelength the absorption caused by melanin decreases significantly.

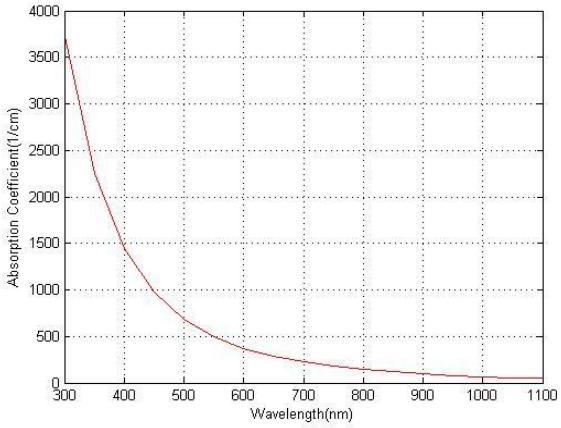

Fig 3: Absorption Coefficient of Melanin

Now there is considerable variation in melanin concentration and colour of skin depends on volume fraction of melanosome in epidermis resulting in different skin types (Type I-VI) [5]. The estimated volume fraction of melanosome (f_mel) is as follows [4]

(i) Light skinned Caucasians f_mel=1.3-6.3%

(ii) Moderately pigmented adults f_mel=11-16%

(iii)Darkly pigmented adults f_mel=18-43%

The total absorption coefficient of epidermis (μ_{a_epi}) after combining both baseline skin absorption and melanin absorption is given by:

$\mu_{a\_epi} = f\_mel * \mu_{a\_mel}(\lambda) + (1- f\_mel)*\mu_{a\_skin}(\lambda)$ (3)

Fig. 4 shows the graphical representation of absorption coefficient of epidermis with 10% volume fraction melanosome.

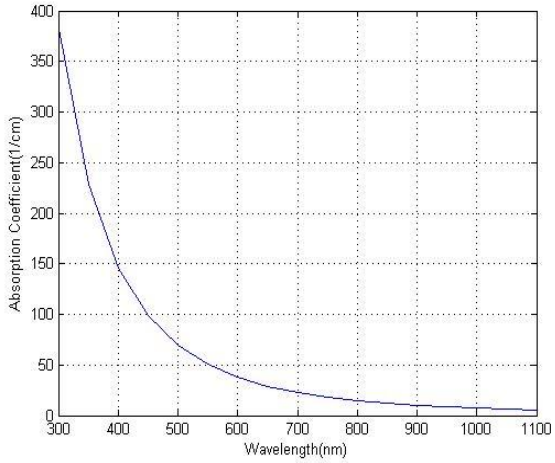

Fig4: Absorption Coefficient of Epidermis with Fmel = 10%

From the above figure it is evident that absorption coefficient of epidermis is high in UV and visible light range and beyond 1100 nm absorption is almost negligible. Similarly for dermis the total absorption considers the contribution of absorption by hemoglobin and minor baseline skin absorption and is expressed as:

$\mu_{a\_derm} = f\_blood * \mu_{a\_blood}(\lambda) + (1- f\_blood)*\mu_{a\_skin}(\lambda)$ (4)

where μ_{a_derm} is the net dermal absorption coefficient, f_blood is the volume fraction of blood in dermis which is approximately 2-5% [4]and μ_{a_blood} isthe absorption coefficient of blood in units of cm^{-1}. Since hemoglobin is the dominant absorber in dermis so we can consider μ_{a_blood} to be equivalent to absorption coefficient of hemoglobin $\mu_{a\_hem.}$. The estimated absorption coefficient of hemoglobin is [6] :

$\mu_{a\_hem}(\lambda) = 0.0054*e_m(\lambda)$ (5)

where $e_m(\lambda)$ is the molar extinction coefficient for the incident wavelength.

Regarding the scattering coefficient there is surely some differences between scattering coefficient of epidermis and dermis but they are not large. So as a generic approach we can consider reduced scattering coefficient of epidermis and dermis are equivalent. The main chromophore causing scattering in epidermis is keratin whereas collagen fibers are responsible for scattering at dermis layer. Here skin scattering is described in terms of relative contribution of Mie and Rayleighscattering. Mie scattering and Rayleigh scattering in dermis can be approximated as :

$\mu_{s'\_Mie(\lambda)} = (2 * 10^5)(\lambda^{-1.5})$ (6)

$\mu_{s'\_Ray(\lambda)} = (2 * 10^{12})(\lambda^{-4})$ (7)

The combination of equation (6) and (7) yields net skin scattering coefficient in unit of cm^{-1} and is given by :

$\mu_{s'}(\lambda) = \mu_{s'\_Mie}(\lambda) + \mu_{s'\_Ray}(\lambda)$ (8)

The refractive index of both epidermis and dermis is higher than that of air. This results in partial reflection (Fresnel reflection) at the tissue interface while the remaining portion gets penetrated through the tissue. As a result of this optical phenomenon there is a change in intensity between the incident light and the emitted light. The light dies away according to the exponential law [3] :

$$I(z) = (1-R)\, I_0 e^{-\mu t * z} \quad (9)$$

where I_0 is incident light intensity, z is sample thickness, $\mu t = \mu_a + \mu_s$ is the extinction coefficient, R is the coefficient of Fresnel reflectionat normal beam incidence and is represented as $R=\frac{(n-n0)^2}{(n+n0)^2}$ where n and n0 are refractive indexes on either side of the interface.

3.2 Instrumental Setup

Light is directed down to the skin via an optical fibre bundle. In our experiment we will be using NIR light (750-950 nm) as it has good penetration power as well as it doesn't have any adverse effect on human skin. The reflected light after being transmitted through different skin layer is transferred back to the photo detector. The photo detector will be connected to a computer to store the data and display the light intensity profile. The block diagram in Fig.5 shows the instrumental setup for the experiment.

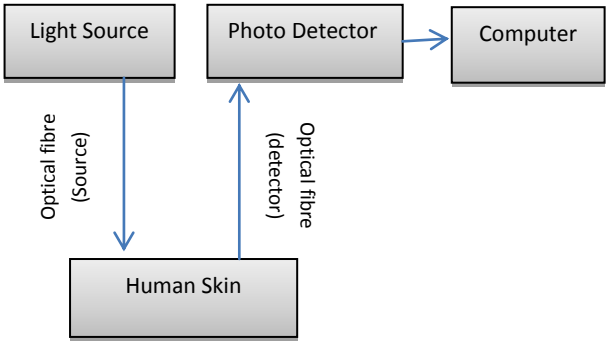

Fig 5: Block Diagram of the Experimental Setup

IV. CONCLUSION AND FUTURE SCOPE

Non-invasive optical body fluid measurement is a most efficient and painless way of diagnosing the problem in human body. But to accomplish such job light has to travel through different layers of human tissue before it reaches its aim. Each of these layers has different optical property and hence affects the path and intensity of the light. In this endeavor we have proposed a mathematical model of scattering and absorption of light through the dermis and epidermis layer. We have considered the well-known properties of these layers and combined them together to generate a general model of absorption and scattering of light in this layer. This will help us detect the intensity and angle of incidence of light in blood. We can also optimize the intensity and angle of the original incident light to get better reading for any inter-body optical measurement. We can extend this model to derive the optical properties of subcutaneous fat layer and blood layer in order to obtain a complete optical profiling of human skin. We can diagnose several abnormalities (e.g. rise of glucose level) in human body by observing the change in optical properties.

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