DEPENDENCE OF ABSORPTION AND SCATTERING SPECTRUM OVER MELANIN CONCENTRATION

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ABSTRACT:

Our health can be strongly affected by exposure to solar radiation. Light interactions relevant for health mainly take place in the skin. Further laser has a property of having high irradiance and penetration power to be used for treatment of several diseases, different medical purposes such as diagnostic, imaging etc. When light interacts with tissue takes place (considering particle nature of laser light), photons get absorbed, scattered or transmitted depending upon the optical properties of the tissue. In this context the optics of human skin is of the extreme importance. Reflection, scattering and absorption are the optical properties affecting the nature of these interactions. This paper provides an analysis of the optical properties of human skin. Included is a description of the primary interactions of light with skin and their strengths and limitations discussed. The optics of human skin has been investigated for more than a century (1). The goal of this paper is to give a brief overview of the primary features of skin optics that is important for human health. Also, we would like to explain the dependence of absorption and scattering properties of human skin over melanin concentration.

KEYWORDS: *Optics of human skin, optical properties of human skin, skin optics, human skin layers, absorption spectrum, scatterers in skin, skin properties*

I. SKIN LAYERS

A. Optical and Structural Characteristics:

The human skin is the outer covering of the body. It is the largest organ of the human body system. It is multilayered structure. Skin is composed of primary three layers: the epidermis, the dermis and the hypodermis.[2]. Epidermis is the outermost layer of the skin. The epidermis is a 0.027-0.15*mm* thick structure [Anderson and Parrish 1981]. It provides a protective barrier over the body's surface. The epidermis can be further subdivided into the following sub layers (beginning with the outermost layer)[3]: Stratum corneum, Stratum lucidum (only in palms and soles), Stratum granulosum, Stratum spinosum, Stratum germinativum (also called the stratum basale). The stratum corneum is composed mainly of dead cells, called corneocytes, embedded in a particular lipid matrix. Absorption of light is low in this tissue, with the amount of transmitted light being relatively uniform in the visible region of the light spectrum. Due to differences in the concentration of melanin, blood, and keratin between them, each of these layers has different optical properties.

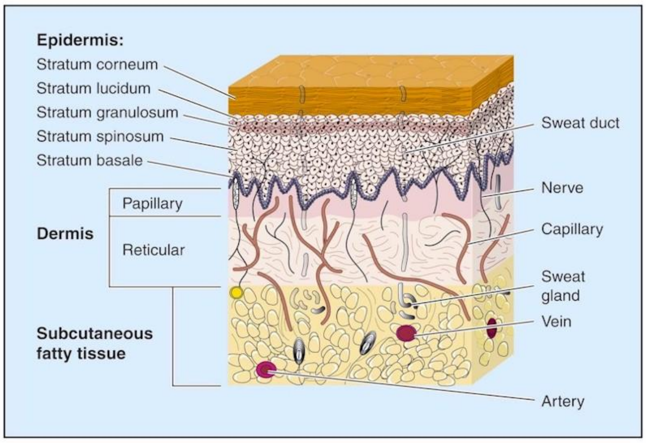

Figure 1 Skin Layers

The light is propagates and absorbs in epidermis. The absorption property appear mostly from a natural chromophore, melanin. There are two types of melanin, the red/yellow phaeomelanin and a brown/back eumelanin, the skin color is mostly associated with the eumelanin [Thody et al. 1991]. Melanin is produced by cells called melanocytes occurring in the stratum basale, and it is found in membranous particles called melanosomes. The melanin absorption level depends on number of melanosomes per unit volume in the epidermis. Usually, the volume fraction of the epidermis occupied by melanosomes varies from 1.3% (lightly pigmented specimens) to 43% (darkly pigmented specimens) [Jacques 1996].

The dermis has a 0.6-3mm thick structure [Anderson and Parrish 1981] which also propagates and absorbs light. Dermis can be divided into two sub layers: the papillary dermis and the reticular dermis as shown in figure 1. These layers are primarily composed of dense, irregular connective tissue with nerves and blood vessels which cushions the body from stress and strain (Smaller ones in the papillary and larger ones in the reticular dermis). The fraction of blood volume in tissue can vary, roughly in the 0.2-7% range [Jacques 1996]. The fluency rate of blood decreases as we get deeper into the skin. In the blood cells we find another natural chromophore, hemoglobin, which absorbs light and gives blood its reddish color. Normally, the hemoglobin concentration in whole blood is between 134 and 173g/L [Yaroslavsky et al. 2002].

Hypodermis is also called as the subcutaneous tissue. Hypodermis is lies below the dermis and it is not part of the skin. Its size varies greatly throughout the body. It can be up to 3cm thick in the abdomen and absent in the eye lids. Its purpose is to attach the skin to underlying bone and muscle as well as supplying it with blood vessels and nerves. It consists of loose connective tissue and elastic (the hypodermis contains 50% of body fat) characterized by a negligible absorption of light in the visible region of the spectrum [Flewelling 1981]. Fat serves as padding and insulation for the body. Due to the fat deposits, most of the visible light that comes to this tissue is reflected back to the upper layers [Doi and Tominaga 2003].

B. Scatters in Skin:

Scattering contributes significantly to the appearance of skin. It describes a change in the direction, polarization or phase of light and it is responsible for surface effects such as reflection or refraction. Approximately 4% to 7% of the light incident (over the entire spectrum) on the stratum corneum is reflected back to the environment, independent of wavelength and skin color [4, 5]. The remaining portion is transmitted to the internal tissues. The scattering in human skin has two main components: surface and subsurface scattering. Surface scattering is affected by the presence of folds in the stratum corneum and it follows Fresnel equations [Su et al. 2002]. Besides of scattering being caused by the reflection and refraction of light at cellular boundaries, two other types of subsurface scattering occur within the skin layers: Mie and Rayleigh scattering [Jacques 1996]. In the dermis, collagen fibers (approximately 2.8μm in diameter and cylindrical [Jacques 1996]) are responsible for Mie scattering, while smaller scale collagen fibers and other micro-structures are responsible for Rayleigh scattering [Jacques 1996]. Light gets scattered multiple times inside the dermis before it is either propagated to another layer or absorbed. This means that the backscattered light from the dermis is diffuse (Jacques et al., [1987]). The stratum corneum and the epidermis are work as forward scattering media [Bruls and van der Leun 1984].The primary scattering particles within the skin are either lipids or proteins embedded in the fluids in and between skin cells. These fluids mainly consist of water. The lipid scatterers are found in the stratum corneum, in the cell membranes.

The scatterers with the dimensions close to the wavelength of the incoming light are the most efficient scatteres with respect to both scattering probability and scattering angle. The primary protein scatterers in skin are keratins and melanins in the epidermis, and collagen and elastin fibers in the dermis. Since melanins have very high refractive indices and are contained within melanosome particles of dimensions varying within the range 0.1 μm – 1 μm(100 nm – 1000 nm) [6,7], are particularly good scatterers. The level of forward scattering for these tissues is wavelength dependent.For both the stratum corneum and the epidermis, scattering profiles are broader towards the shorter wavelengths.

c. Absorbers in skin: Light get absorbs in the skin mainly due to three absorbers: Blood [8], melanosomes[9], keratin[10].

c1. Blood:

Since the blood vessels and capillaries are found only below the epidermis in which many of the primary optically induced processes related to human health occur, *i.e.* skin cancer induction and pre-vitamin D3 photo production. It is, however, important to mention that even though the blood is found beneath the epidermal layers, the amount of blood does affect the amount of UV and visible light that reach these layers.

The main blood absorption bands can be seen in Fig. 2 between the wavelengths 400 and 425 nm (violet light) and the wavelengths 500 and 600 nm (green light). At wavelengths longer than 600 nm (red and near infrared light) the blood absorption is very low. This wavelength dependence of the absorption is the reason for the red color of blood.

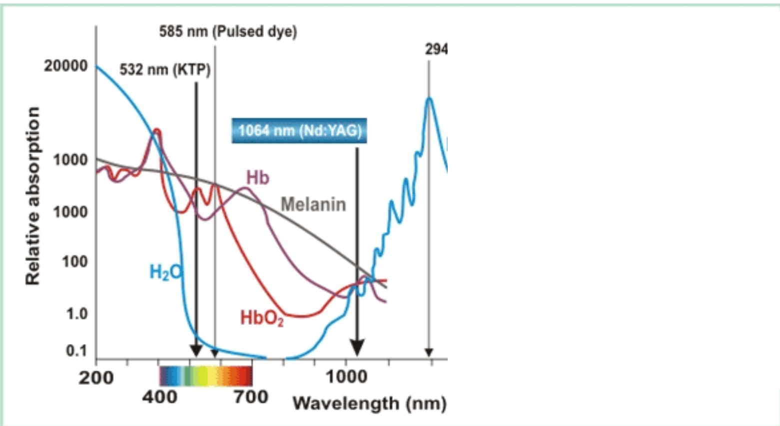

Figure 2 Absorption spectrum for different chromophores

c2. Melanin:

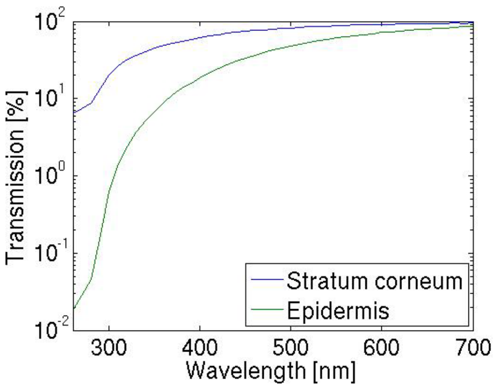

Figure 3

Figure 3 shows the transmittance of the stratum corneum (upper curve) and of the entire epidermis (lower curve) in the wavelength regions UVB, UVA and visible light for a volume concentration of 15% melanosomes in the epidermis[11-13]. As can be seen in fig 3, the transmittance is high in the visible spectral region (20%-90%), decreases through the UVA spectral region from 20% to 2%, and decreases further in the UVB spectral region from 2% to 0.2%.

c2.1. Variation Due To Melanin Concentration:

Further, we have plotted another graph to study the effect of melanin concentration on the light ray propagation. To find this, a graph is drawn between remitted light intensity and angle of incidence with skin types of varying melanin concentration i.e. caucasian, negroid and light brown colored skin. The absorption increases steadily with decreasing wavelength into both the UVA and UVB spectral regions.Also the effects of increasing the melanosome concentration in the skin are relatively small at wavelengths shorter than 300 nm, in view of the fact that the melanosome absorption at these short wavelengths is higher than those at longer wavelengths. The reason is that the absorption by proteins (mainly keratin) in the epidermis surrounding the melanosomes increases relatively more strongly with decreasing wavelength into the UV spectral region than the absorption by the melanosomes.

At Wavelength =700nm

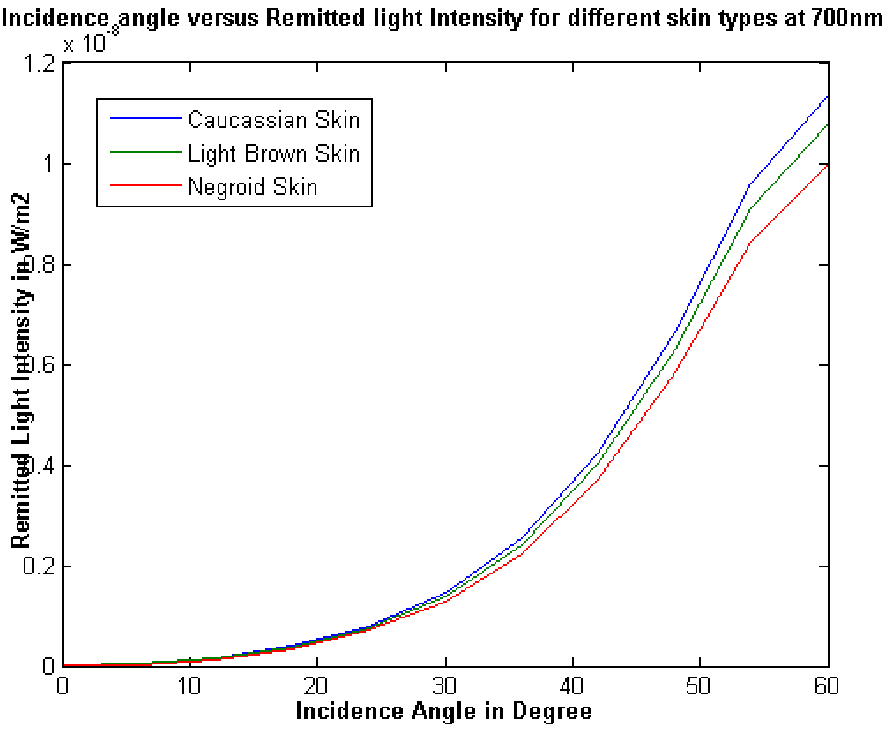

Figure 4

This graph is drawn at λ=700nm , The melanin concentration by varies as follows-
For Caucasian Skin- 1.3%-6.3% as volume fraction.
For Light Brown or moderately pigmented Skin- 11%-16% as volume fraction.
For Negroid Skin- 18%-43% as volume fraction.

It clearly indicates that as the melanin concentration increases, the remitted light intensity reduces as it is maximum for Caucasian and least for Negroid, which makes it very much evident that melanin pigmentation account for attenuation of light. We have also drawn two more similar graphs at a lower and a higher wavelength as shown in the following.

At Wavelength =500nm

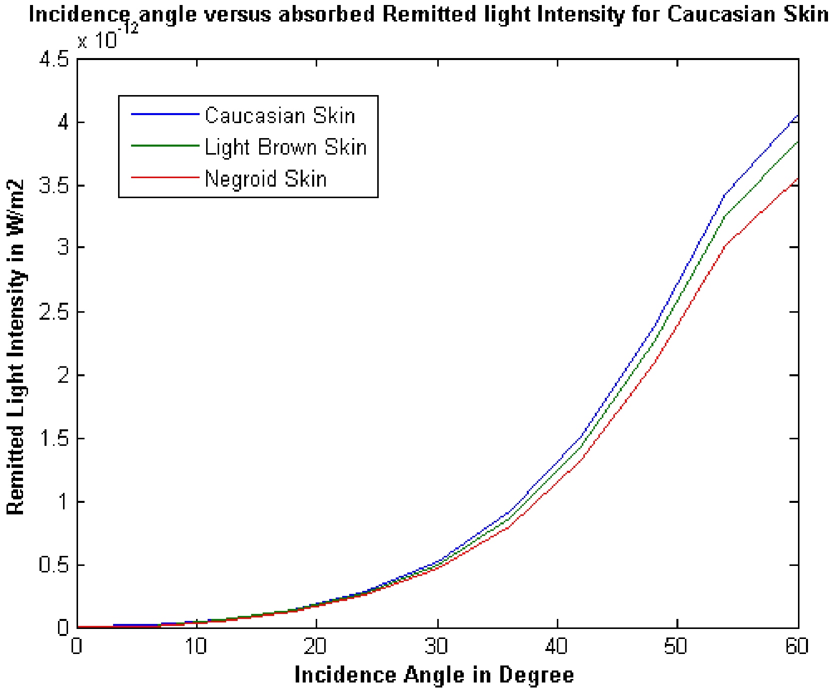

Figure 5

At Wavelength =900nm

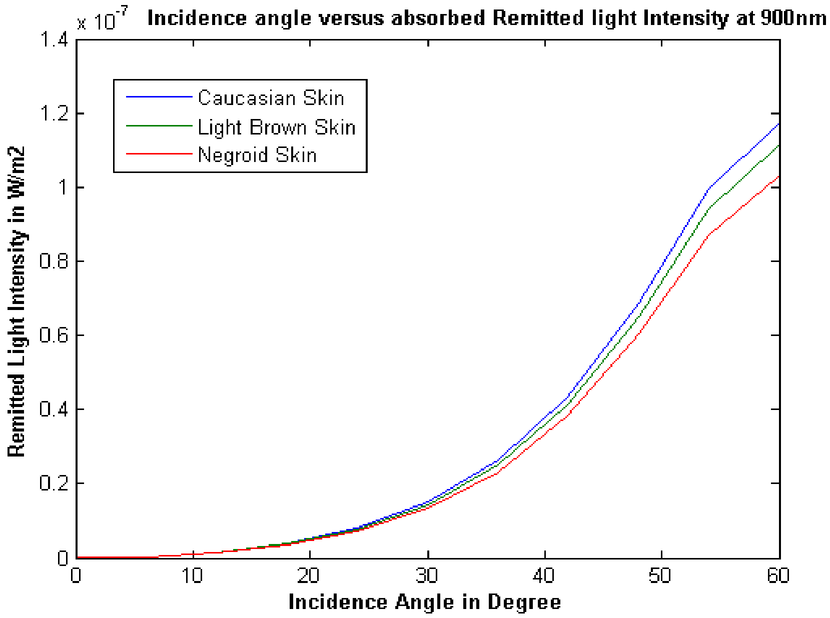

Figure 6

c3. Keratin

Keratin is a main component of the epidermis and, in particular, of the stratum corneum. It is what nails, hairs and horns are made of. In Fig. 5 an apparent absorbance spectrum of keratin is shown. keratin almost exclusively absorbs UV radiation with a maximum at approximately 280 nm.

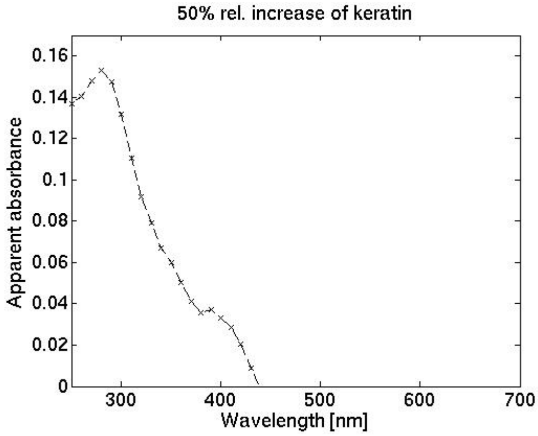

Figure 7 The apparent absorbance of a 50% relative increase of epidermal keratin in the wavelength regions UVB (280-320 nm), UVA (320-400 nm) and visible (400-700 nm).

II. CONCLUSION

Noninvasive and real-time analysis of skin properties is useful in a wide variety of applications. Biological and optical analysis of human skin tissue is presented in details, which gives an insight of multi layered skin structure. This study gives the benefit of using it in any kind of dermatological issues to know about the effects of harmful radiations such as UV light. Moreover, this report gives a graphical analysis for skin response to a light ray at different wavelengths, for different incident light intensities and for different kind of skin structure such as for Caucasian, Negroid and average pigmented skin. These results can be helpful in analyzing different kinds of skins at different scenarios.

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