Characterization Of Pathological Skin Sample By Polarimetric Technique

Anil Gupta[*1], CLP Gupta[2], Purnima Bharti[3] and Devash Kumar[4]

ABSTRACT

Measurement of optical properties of skin is an expanding and growing field of research. Recent studies have shown that the biological tissue, especially skin changes the polarization state of the incident light. Using this property will enable the study of abnormalities and diseases that alter not only the light intensity but also its polarization state. We have tried an experimental study for measuring changes of polarization state of the light scattered from skin sample. Using the strokes vector and Mueller matrix notation we have shown that some elements of matrix were sensitive to the changes of the polarization when physical properties of the scatters are changed with sample.

Keywords: *He Ne Laser 632.8 nm, Polarimeter, Pathological Sample*

1. INTRODUCTION

Development of appropriate diagnostic techniques for measuring and monitoring skin abnormalities is currently one of the challenging areas of research [3-5]. Most of diagnostic methods and evaluation methods for measuring the progress of skin disease are based on visual examination by dermatologists [14]. Therefore, reliability and repeatability of such methods are almost questionable. Skin shows absorption and scattering properties when it is exposed to light. Most of available methods are based on measuring intensity of reflected, scattered or transmitted light. Techniques like microscopy or dermatoscopy are able to only diagnose physical parameters that make changes to the light intensity [14]. Researches have shown that biological tissue can affect the polarization state of the incident light. The main polarization-altering agents of skin are scattering particles like nuclei cells and mitochondria, and collagen fibers that demonstrate birefringent effect [11]. Development of skin abnormalities can also change the polarization state of the scattered light [8]. Therefore, the progress of such diseases could be measured and monitored by measuring the changes in the polarization state.

Polarized light can be represented mathematically by a 4×1 vector known as the Stokes vector [9-12]. By measuring the Stokes vector of the scattered light from an object and comparing its elements with those of the incident light, we can obtain a 4×4 matrix known as the Mueller matrix characterizing the object under study. Each of the 16 elements of the Mueller matrix depends on the polarization-altering features of the object affecting the polarization state of the light. Polarization-altering components of skin could illustrate different polarization properties based on their shape, size, composition, structure, etc. The objective of this paper is to show the sensitivity of some elements of the matrix to the changes of physical properties of scatterers and collagen fibers, using the notation of

1*. Anil Gupta (Researcher): Department of Physics, University of Lucknow, Lucknow (India), E-Mail ID: dpcgupta@gmail.com
2. C.L.P. Gupta: Department of Computer Science & Engineering, School of Management Sciences, Lucknow (India), E-Mail ID :clpgupta@gmail.com
3. Prof. P. Bharti, Department of Physics, University of Lucknow, Lucknow (India), E Mail ID: pbharti2@gmail.com
4. Devash Kumar: Department of physics, BBA University Lucknow (India), E Mail ID: dkclcre@yahoo.com

Stokes vector for the polarized light and Mueller matrix for the skin. We have used a polarimetric experimental setup to measure the elements of the Mueller matrix of three different skin sample. Our results have shown that polarimetry is a valuable technique that can be used for measuring the change in scattering and polarization properties of skin and can be developed as a suitable diagnostic tool for measuring skin abnormalities.

2. THEORY

In polarimetry, a beam of light of arbitrary polarization is represented mathematically by a 4×1 column vector known as the Stokes vector. Its elements, the Stokes parameters, are usually labeled *I, Q, U,* and *V,* and defined in terms of electrical field amplitudes parallel $E_{Q\%}$ and perpendicular $E_{¥''}$ to the scattering plane.

$$I = \langle E_{\parallel}E_{\parallel}^{*} + E_{\perp}E_{\perp}^{*} \rangle = I_H + I_V$$

$$Q = \langle E_{\parallel}E_{\parallel}^{*} - E_{\perp}E_{\perp}^{*} \rangle = I_H - I_V$$

$$U = \langle E_{\parallel}E_{\perp}^{*} + E_{\perp}E_{\parallel}^{*} \rangle = I_P - I_M$$

$$V = i\langle E_{\parallel}E_{\perp}^{*} - E_{\perp}E_{\parallel}^{*} \rangle = I_R - I_L$$

where parameters are defined as follows *, complex conjugate < >, time averaging over the interval long compared with the period $E_{Q\%}$, amplitude of electric field parallel to the scattering plane $E_{4\%}$, amplitude of electric field perpendicular to the scattering plane I, light intensity H, horizontal state of polarization V, vertical state of polarization P, $+45^0$ linear state of polarization M, -45^0 linear state of polarization R, right circular state of polarization L, left circular state of polarization.

It can be shown that, in general, $I^2 \geq Q^2 + U^2 + V^2$. The equality holds if the light is strictly monochromatic or completely polarized. For unpolarized light, Q=U=V=O. In general, the degree of polarization (DOP), degree of linear polarization (DOLP) and degree of circular polarization (DOCP) can be Calculated from Stokes elements using

$$DOP = \sqrt{Q^2 + U^2 + V^2 / I}$$

$$DOLP = \sqrt{Q^2 + U^2 / I}$$

$$DOCP = V / I$$

In order to study the variation of polarization properties caused by a certain sample, a set of crosstalk polarization parameters is defined. In this way, the horizontal-to-vertical crosstalk (HVC) is determined for an horizontally polarized incident beam, being defined as the ratio:

$$HVC = \frac{par - perp}{par + perp}$$

Where *par* corresponds to the intensity of the horizontal polarization output component when irradiating the tissue with horizontally polarized light, and perp. is the intensity associated to the vertical component. The vertical-to- horizontal, left-to-right and right-to-left crosstalk parameters can be defined in an analogous way. All these parameters are in the range of [-1, 1]. On one hand, if they take the value of I, it means that the corresponding polarization state is maintained. On the other hand, a value of -1 corresponds to a situation in which a concrete incident polarization state would result in the opposite polarization state.

Biological tissues present a very high degree of heterogeneity. They are known to be a turbid medium in general, i.e. they strongly depolarize the optical radiation when irradiated with a light beam. Due to this fact, the Mueller calculus is a very useful polarimetric technique in order to study polarization dependent interaction between light and tissues, as long as it can manage partial polarized light beams and devices that cause depolarization [7].

3. EXPERIMENTAL SETUP

For Mueller matrix imaging, we need samples to start with. For this three different tissue samples have

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been studied. The pathologist earlier diagnosed one of them malignant. The samples measured in this work were brought from GSVM Medical College, Kanpur. To measure the polarization state of light being scattered from the sample a number of different skin sample were taken and used for the measurements. These included human skin. We used three different types of skin sample. The first type healthy skin, second type benign mole size skin and the third type malignant skin.

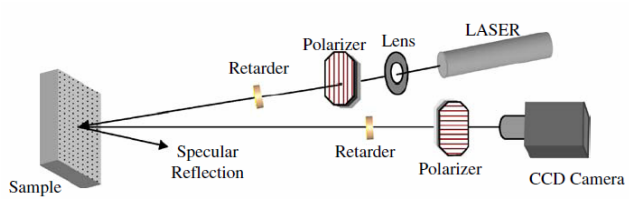

Fig. 1. Experimental Setup

We set up a laboratory-based scattering polarimetric system using appropriate optical devices, such as a laser source (HeNe laser, A=632.8 nrn,), two wide band polarizer plates, two quarter (1/4) wave plates (retarders), two collimating lenses to focus laser on the sample and to collect the scattered light from the sample, and an optical detector. The schematic diagrams of the system are shown in Figure (i). A photograph of the system is shown in Fig.(ii), (iii), (iv). The light source, lens, polarizer and retarder form the polarization state generator (PSG) unit. The PSG unit generates the polarized light. After interaction with the sample, the scattered light is received by the polarization state detector (PSD) unit that consists of lens, retarder, polarizer, and optical detector. To make the 16 independent elements of the Mueller matrix. So, we had to make 4 individual polarimetric measurements with 4 different incident polarized light states (vertical, horizontal, +45°, and right circular).

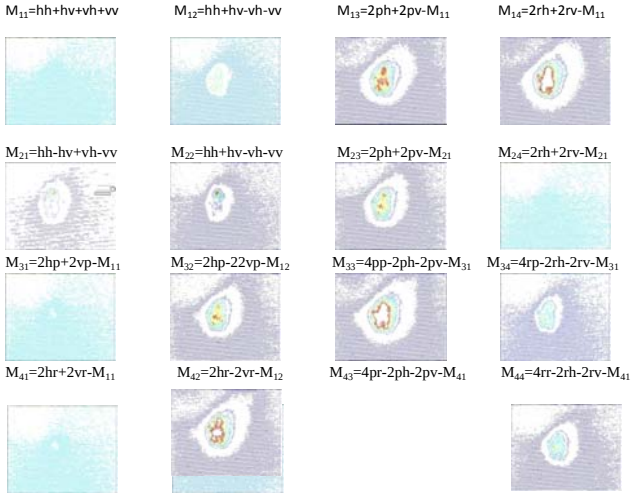

Fig.2. Contour Mueller Matrix Of Healthy Skin Sample

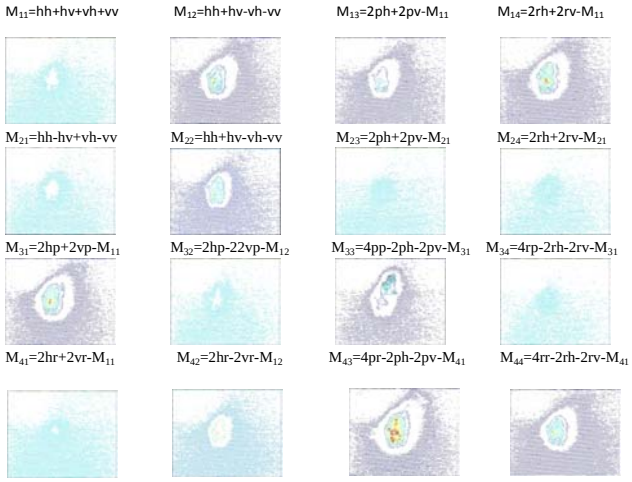

Fig.3. Contour Mueller Matrix Images Of Benign Mole Size Sample

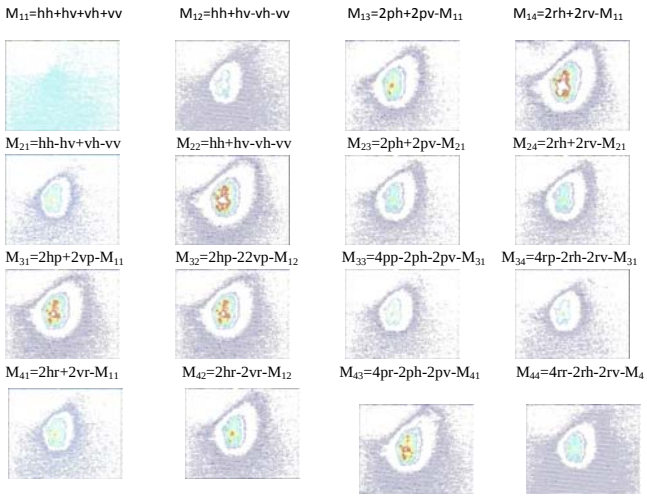

Fig.4. Contour Mueller Matrix Images Of Malignant Skin Sample

4. RESULT

Healthy Skin

1	0	0	0
- 0.04	0.3	-0.06	0
0.02	-0.04	-0.2	-0.016
-0.016	0.03	0	-0.22

Benign Mole Size

1	0	0.01	0.004
-0.02	0.56	-0.13	0
0.3	-0.1	-0.4	-0.001
-0.03	0.06	0.01	-0.44

Malignant Skin

1	-0.08	0.007	-0.06
-0.1	0.54	-0.15	0
0.3	-0.11	-0.504	-0.001
-0.035	0.08	0	-0.55

The Mueller matrices have been measured in backscattering configuration for a wavelength of 632.8 nm with such a detection angle that the specular reflection is avoided. The resulting matrices are shown above.

From these matrices, the Lu-Chipman polar decomposition is applied, and then the depolarization power of each sample has been calculated. The results are shown in table 2. It can be observed that normal skin depolarizes light in a strong way. Benign mole depolarizes less, and the malignant sample produces the lower depolarization.

Table - 1
Depolarization Power of the Samples Measured

Depolarization of Healthy skin	0.618
Depolarization of Benign mole	0.386
Depolarization of Malignant Skin	0.267

As well as the depolarization power, we have calculated a series of degrees of polarization. The notation used here are DOLP, DOTP, DOCP, means degree of linear polarization, degree of total polarization and degree of circular polarization and subscript denotes the polarization state of irradiated light. The results for linear polarization states are included in Table 2, while Table 3 shows the parameters for the circular ones.

Table - 2
Degree of Linear Polarization

	$DOLP_H$	DOT_H	DOL_V	DOT_V
Healthy Skin	0.2417	0.2511	0.3469	0.3588
Benign Mole	0.5825	0.5844	0.7127	0.7188
Malignant Skin	0.6244	0.6173	0.7725	0.7880

Table - 3
Degree of Circular Polarization

	$DOCP_R$	$DOTP_R$	$DOCP_L$	$DOTP_L$
Healthy Skin	0.2440	0.2424	0.2140	0.2207
Benign Mole	0.4624	0.5600	0.4070	0.5054
Malignant Skin	0.6180	0.7145	0.4724	0.5542

In order to obtain more information about the polarization behavior of the samples, we have also calculated the polarization crosstalk parameters included in Table 4. They do not present any type of strong crosstalk between polarization states.

Table - 4
Polarization Crosstalk Parameters of the Samples

	HVC	VHC	RLC	LRC
Healthy Skin	.2400	.3400	-0.2550	-0.2050
Benign Mole	.5400	.5800	-0.4613	-0.4070
Malignant Skin	.5834	.6678	-0.6381	-0.4810

The depolarization power observed for each sample shows a clear difference between them. Depolarization in biological tissues is mainly related to scattering, and therefore it varies with the number of scattering events undergone by the photons, as well as with the density of scatterers, their dimensions and

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their composition [11]. We hypothesize that the main factor that affects the depolarization power is related to the absorption coefficient, and in particular to the melanin content, as long as it is the most relevant histopathological characteristic of the tumorous lesion considered in this work. Skin absorption is dominated by melanin that shows a strong absorption in the visible range. It is the dominant chromophore in skin. Therefore, the absorption coefficient of skin directly depends on the melanin presence. Melanin is contained in the melanosomes. Mole are characterized by a higher melanosome content than healthy skin. In the case malignant skin melanocytes continue to produce melanin in their cancerous state. Therefore, as the tumor grows, melanosomes diffuse in the epidermis layer and, depending on the cancer stage, can also appear in the dermis [13]. This causes that, in the particular melanoma type considered in this work, the tumorous tissue shows a very high melanin content. This has a double effect: both the penetration depth and the amount of back scattered light are drastically reduced. We propose that, as long as light penetrates less into the tissue, it undergoes less scattering events, suffering less depolarization. It is known that cancerous tissues typically show increased blood perfusion compared to normal tissues. In particular, malignant skin usually has a peripheral blood net around it in order to obtain enough nutrients to maintain its growth [11]. The results included in Tables 2 and 3 show the degree of linear polarization and degree of circular polarization for healthy skin, benign mole, and malignant skin sample. Table 4 shows the cross talk parameters for different pairs of polarized light.

5. CONCLUSION

The depolarization power has been proved to show a significant difference between healthy skin, being a mole, and malignant skin. We have hypothesized that it is due to the melanin content of the skin samples considered, based on its optical properties effects as well as the fact that it is the most relevant histopathological feature observable in beingn mole and malignant samples in comparison with healthy skin. However, there are more factors that should be studied in future works in order to achieve a better knowledge about this pathology and its detection possibilities by means of optical techniques.

In this paper, we presented the application of polarimetric technique for measuring polarization properties of skin. We carried out measurements of elements of the Mueller matrices of skin samples.

The above results show the applicability of the polarimetric technique that can be developed by designing an appropriate system for measuring polarization properties of skin in a clinical laboratory. The sensitive elements of the Mueller matrix can represent biomarkers of polarization-dependent scattering and birefringent elements of the skin in such studies.

REFERENCES

[1] K.K. Shung, M.B. Smith, and B.M.W. Tsui, *"Principles of Medical Imaging"*, Academic Press, Inc., 1992.

[2] Soiderchuk, R. I. "*Laser polarimetry of conjunctive bio-tissue*" SPIE, 4705: 194-202, 2002.

[3] Andreassi, L., Rubegni, P., Burroni, M., "*Digital technology in dermatoscopy*" Gital, Dermatol, Venereol., 139: 449-454, 2004.

[4] Matuszak, Z., Radwanska, M., *Optical properties of melanin solutions, Estimation of polymer particle size symp. on photonics technologies for 7th framework program* Wroclaw 2006.

[5] Skvara, H., Teban, L., Fiebiger, M., Binder, M., Kittler, H., "*Limitations of dermoscopy in the recognition of melanoma*" Arch. Dermatol., 141(2): 155-160, 2005.

[6] Amos., W.B., White, J. G., "*How the confocal laser scanning microscope entered biological research*" Biology of the cell, 95(6): 335-342, 2003.

[7] Baba, J. S., Chung, J.R., Delaughter, A.H., Cameron, B.D., Cote, G.L., "*Development and calibration of an automated Mueller Matrix polarization imaging system*" Biomed. Optics, 7(3): 341-345, 2002.

[8] Azzam, R. M. A., Bashara, N.M., "*Ellipsometry and polarized light*" Amsterdam, North Holland, ISBN: 978-0-444-87016-2, 1987.

[9] Bohren, C., Huffman, D.R., "*Absorption and scattering of light by small particles*" Wiley Science Series, ISBN: 978-0-471-29340-8, 1998.

[10] Yao, G., Wang, L. V., "*Propagation of polarized light in turbid media, simulated animation sequences*" Optics Express, 7(5): 198-203, 2000.

[11] S. Y. Lu and A. Chipman, "*Interpretation of Mueller Matrix Based on polar decomposition*" J. Opt. Soc., A 13, 1106-1113: 1996.

[12] D. Goldstein, "*polarized Light*" Marcel Dekker, Inc., New York: 2003.

[13] S. L. Jacques, J. R. Roman, and K. Lee, "*Imaging superficial tissue with polarized light*" Lasers Surg. Med. 26, 119–129: 2000.

[14] M. H. Smith, "*Interpreting Mueller matrix images of tissues*" In Proc., SPIE 4257, 82–89: 2001.

