Journal of the Optical Society of Korea, Vol. 7, No. 4, December 2003, pp. 234-239

Polarization Spectral Imaging System for Quantitative Evaluation of Port Wine Stain Blanching Following Laser Treatment

Byungjo Jung*

Beckman Laser Institute, University of California, Irvine CA 92612-1475, USA

(Received September 24, 2003)

Objective methods to assess quantitatively port wine stain (PWS) blanching in response to laser therapy are needed to improve laser therapeutic outcome. Previous studies have attempted to assess objectively PWS color based on point measurement devices. To date, these approaches have typically been limited by a number of factors such as small test area and need for contact. To address these issues, a polarization spectral imaging system and an image analysis method have been developed to evaluate quantitatively erythema and melanin content distribution in skin. The developed polarization spectral imaging system minimizes artifacts such as glaring, shadowing, and non-uniform illumination that interfere with image fidelity. Furthermore, the image analysis method has been employed to get images of skin melanin and erythema indices from the acquired color images for quantitative analysis. Finally, using PWS patient color image, the effectiveness in laser treatment of PWS was evaluated by calculating relative erythema index image that is the relative erythema index of PWS region to the normal region. The developed device and analysis method appears to be a simple and effective method for quantitative analysis of PWS blanching.

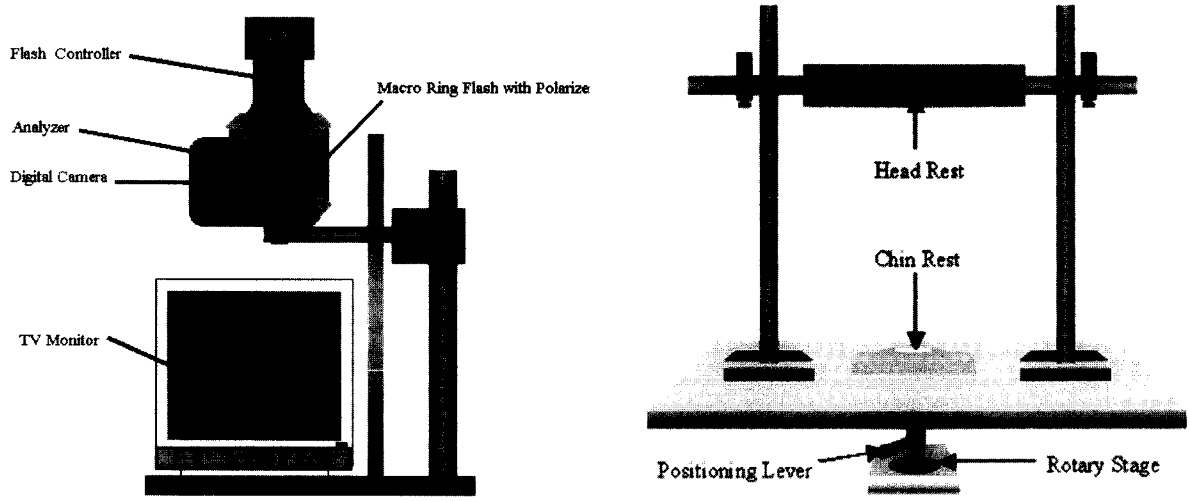
OCIS codes : 170.0110, 170.1870, 170.3880, 170.6510.

I. INTRODUCTION

Port wine stains (PWS) are congenital hypervascular cutaneous malformations that occur typically on the face and neck. PWS patients may experience physical and emotional disability due to facial asymmetry and deformity. Pulsed dye lasers (PDL) are used for the clinical management of PWS patients [1-6]. To destroy PWS blood vessels permanently, PDL light at 585 or 595 nm wavelengths is absorbed preferentially by hemoglobin and converted to heat, resulting in vessel injury. Therapeutic outcome varies in large part due to site-to-site and interpatient variability in the following skin characteristics: epidermal melanin absorption, PWS depth and blood vessel size [4,7,8].

Previous studies have demonstrated that clinical judgment of PWS skin appearance before and after laser treatment is strongly correlated with skin erythema [9,10]. Commercial devices, such as reflectance spectrophotometers and tristimulus colorimeters, can provide quantitative information on skin erythema and melanin. A reflectance spectrophotometer emits light at green and red wavelengths for quantification of erythema and melanin content, respectively [9–14]. A photodetector detects the reflected light, and erythema index (E.I.) and melanin index (M.I.) are computed. Alternatively, the tristimulus colorimeter illuminates skin with white light and reflected light is detected by three filtered photodiodes sensitive to either red, green, or blue (RGB) light [11,14]. The RGB data is subsequently converted to the Commission Internationale de l'E'clairage (CIE) L*a*b* color space [15]. Previous studies have shown that a* and L* values represent the degree of skin erythema (hemoglobin content) and the degree of skin pigmentation (melanin content), respectively [15–18].

Although these reflectance measurement techniques can provide valuable information on PWS skin erythema and melanin content, they are limited in usefulness by practical considerations such as small test area and potential skin blanching due to probe contact, average measurement on test area, and low reproducibility at the same site. An alternative technology is to use a digital camera based system, which offers advantages such as computer interface for near



(a) (b)

FIG. 1. Schematic diagram (a) of the polarization spectral imaging system and (b) of the head positioning device used to standardize images obtained from each subject.

real time feedback, flexibility of measurement area selection, and noncontact technique, [19–23]. However, for a digital imaging system to provide meaningful results, several factors must be controlled, such as camera sensitivity, shutter speed, aperture size, magnification, and patient positioning for consistent image analysis. Although those factors might be controlled, image quality may be affected by glare, shadowing, nonuniform illumination, and environmental lighting.

To address such issues of current methods in quantitative PWS assessment, a polarization spectral imaging system and image analysis methods were developed and utilized to perform a quantitative measurement of erythema and melanin content in skin. Finally, the utility of the system for quantitative assessment of the blanching response of PWS skin after laser therapy was presented.

II. EXPERIMENTS AND RESULT

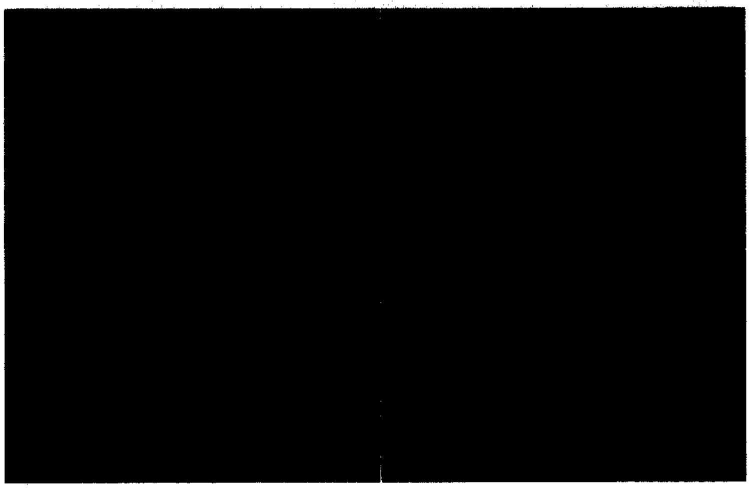
1. Polarization Spectral Imaging System

A digital color camera (Model DiMAGE7, Minolta Co., Osaka, Japan) was used to acquire images from PWS patients (Fig. 1(a)). The camera provided RGB images with 8 bits per color channel and sensor dimensions of 2560 × 1920 pixels. A macro ring flash (Model 1200, Minolta Co., Osaka, Japan) controlled by a flash controller provided shadow less and uniform illumination. To reduce glare caused by specular reflectance from the skin surface, a linear polarizer (Model A45-669, Edmund Industrial Optics, Barrington, NJ) was placed in front of the macro ring flash; a second identical polarizer (analyzer) was placed in front of the camera lens. Both were positioned such that their polarization axes were orthogonal. Camera output was displayed on a 9" color monitor (Model PR 0935B, Philips Magnavox, Atlanta, GA). To eliminate artifacts induced by environmental lighting, digital images were acquired in the dark. Camera settings were identical for all acquired images. To ensure that test sites identified on the skin were positioned in a reproducible manner, a custom device (Fig. 1(b)) consisting of head and chin rests mounted on a rotary stage allowed for subject positioning at angles between 0° (front profile) and 90° (side profile).

2. *In Vivo* imaging of PWS skin

Digital images were acquired from a patient undergoing laser therapy at Beckman Laser Institute for a PWS on the left cheek. When the subject's head was positioned comfortably, the imaging angle was set to 45° with respect to the camera optical axis in order to image the entire PWS while minimizing artifacts induced by facial curvature. All data were acquired in accordance with a protocol approved by the Institutional Review Board at University of California, Irvine.

The specular reflectance, apparent as glare in general digital color image, overwhelms color information evident in the absence of glare. However, specular reflectance affecting the image quality was removed in the cross-polarized color image as shown in Figs. 2 (a) and (b) that present PWS patient's images before



(a) (b)

FIG. 2. Color images before (a) before and (b) after pulsed dye laser treatment taken with polarization spectral imaging system. The time interval between image (a) and (b) was 8 weeks.

and after pulsed dye laser treatment, respectively.

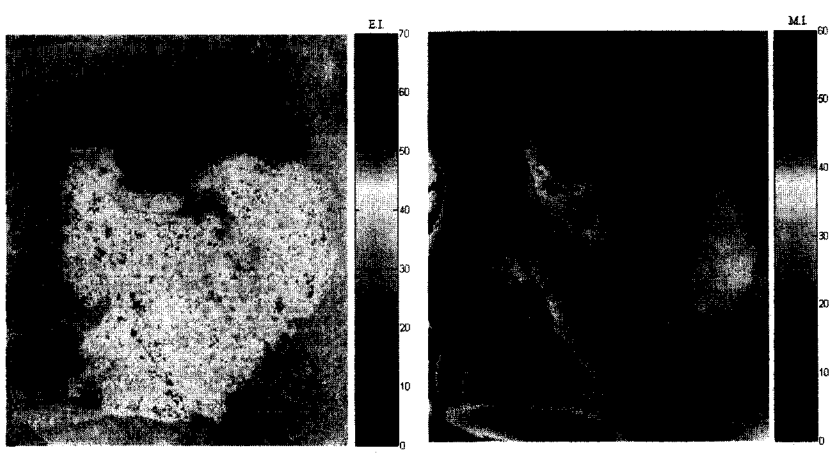
3. Image Analysis Method

Like reflectance spectrophotometry, color images acquired with our imaging system can be also utilized to acquire quantitative chromophore information because the color images include spectral information of the targeted sample in terms of the reflected intensity of red (R), green (G), and blue (B) light. With the acquired cross-polarized color images, image analysis was performed with custom software written in MATLAB (Version 6.1, The MathWorks, Natick, MA). Diffey algorithm [24,25] previously descried in study of M.I. and E.I. was utilized to calculate E.I. and M.I. image from the acquired RGB image. In there, the absorbance index defined by Dawson *et al* was used [26]. The algorithm was described in Eqs. (1) and (2) as following.

$$\text{E.I. image} = 100 \times \log_{10}(R_r/R_g) \quad (1)$$

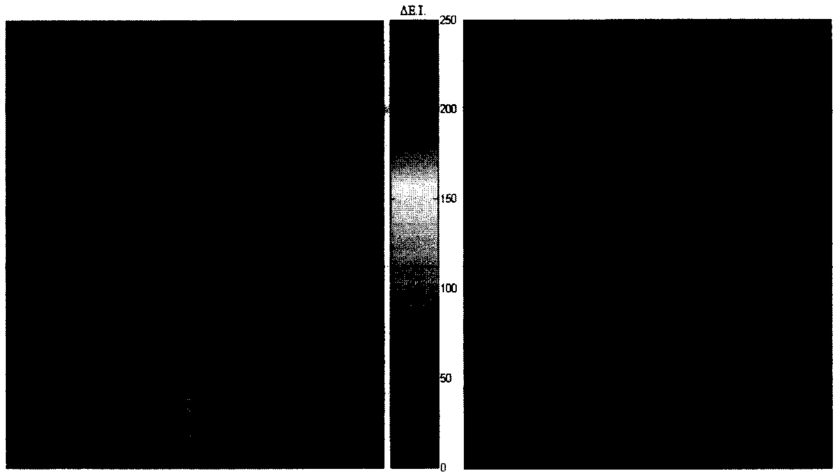
$$\text{M.I. image} = 100 \times \log_{10}(1/R_g) \quad (2)$$

where $R_{r,g} = S_{r,g}/W_{r,g}$ and the 'r' and 'g' indicate red and green, respectively. $R_{r,g}$ is the normalized sample (patient) reflectance image of red and green color, $W_{r,g}$ is average red and green value of 99% diffuse reflectance white standard that is used as reference for normalization and $S_{r,g}$ is the red and



(a) (b)

FIG. 3. (a) Erythema index (E.I.) image and (b) melanin index (M.I.) image. In both cases, a higher value indicates higher degree of the erythema and the melanin content. PWS regions in erythema index image presented higher E.I. compared to the normal regions.



(a) (b)

FIG. 4. Relative erythema index (ΔE.I.) images (a) before and (b) after pulsed dye laser treatment. Image (a) and (b) were calculated from images of Figs. 2(a) and 2(b), respectively. The solid white lines in each image denote normal skin regions used in calculation of ΔE.I..

green color image of the sample. In both images, the higher index value denotes the higher degree of melanin and hemoglobin contents.

With the 99% diffuse reflectance white standard image, the RGB values as reference for normalization were computed and determined as 251.7, 253.7 and 252.1, respectively, with standard deviations of ~1. Figs. 3 (a) and (b) are E.I. and M.I. images, respectively, derived from the patient RGB color image acquired before laser treatment (Fig. 2(a)). The color bars in Figs. 3(a) and (b) denote quantitative measures of skin erythema and melanin content, respectively. Higher E.I. and M.I. values denote more pronounced PWS skin erythema and melanin content.

Utilizing Eq. (1), quantitative assessment of before and after PWS laser treatment result was performed as follows: E.I. image was first calculated from the acquired RGB images including both normal and PWS skin and then, a relative E.I. image in percent scale, ΔE.I., was computed using the following equation:

$$\Delta\text{E.I}(\%) = [(\text{E.I.}_{Pws} - \text{E.I.}_{Ns})/\text{E.I.}_{Ns}] \times 100 \quad (3)$$

where E.I._{Pws} represents the erythema index image of the entire skin including PWS lesion and E.I._{Ns} is the average erythema index of the selected normal skin. Thus, ΔE.I. represents the relative erythema index image of PWS lesion to average erythema index value of selected normal skin. Therefore, ΔE.I. in PWS lesion will approach 0% when the erythema index of the PWS lesion decreases and finally approaches the E.I. of normal skin in consecutive laser treatments.

To demonstrate the relative degree of erythema in PWS lesion versus normal skin, ΔE.I. images were computed and presented in Figs. 4(a) and (b). The three different regions outlined as boxes by solid white lines in Figs. 4(a) and (b) were selected as representative normal skin. Average normal skin values E.I._{Ns} of before and after laser treatment images (Figs. 4(a) and (b), respectively) were 24.30 and 24.89, respectively. After laser treatment, ΔE.I. values were reduced as compared to corresponding PWS areas before treatment. Using ΔE.I. images, histograms of before and after treatment were computed for further visualized numerical comparison and to show another example of versatile utilities of image analysis in this application and presented in Fig. 5. The average values of 20 by 20 pixels in the entire PWS lesion were computed to minimize data size for the histogram. The histogram after laser treatment has moved to

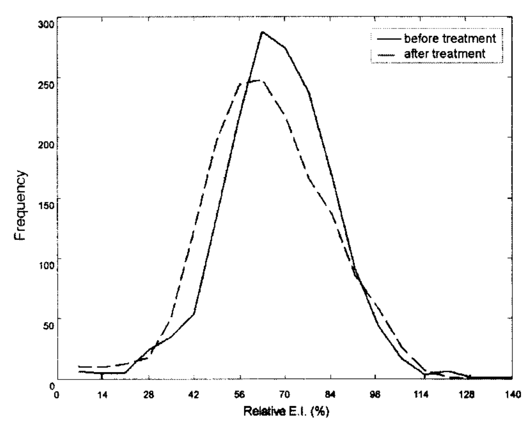


FIG. 5. Histogram of relative erythema index (ΔE.I.) variation computed from before (FIG. 4(a)) and after (FIG. 4(b)) laser treatment images. The histogram after treatment compared to before treatment moves to the lower ΔE.I. with less frequency, presenting blanching effect of laser treatment.

lower relative E.I. with less frequency, showing further PWS clearing after treatment.

III. CONCLUSION

An advantage of our polarization spectral imaging system is the use of polarization optics to remove surface glare. When light is incident on skin, ~5 % is reflected due to the refractive index mismatch between human skin and air. Such specularly reflected light contains information on the superficial texture of the skin surface. However, specular reflectance impairs observation of skin color information provided by light scattered and absorbed from subsurface structures. Thus, an image of skin taken without crossed polarizers contains information on surface morphology (in the form of specular reflectance) and skin pigmentation and degree of vascularization (in the form of diffuse reflectance). Since specularly reflected light is in the same polarization state as incident light, a crossed polarizer was used to remove unwanted specular reflectance, resulting in images containing primarily subsurface information on skin chromophore content (Figs. 2 (a) and (b)).

Vascular and pigmentation skin disease can be quantitatively evaluated using E.I. and M.I. image calculated with RGB images of polarization color image, respectively. Figs. 3(a) and 3(b) present E.I. and M.I. images of the PWS patient, respectively. In the case of PWS that is the vascular disease, examination of an E.I. image provides quantitative information on PWS skin color.

Our image analysis method was also applied to evaluate PWS blanching after laser treatment. Ideally, the degree of erythema should be decreased with each successive treatment. To observe the blanching effect, an E.I. image was computed prior to each successive laser treatment and compared to previous images. However, by using only an E.I. image for comparison, determination of treatment efficacy may be inaccurate because of variations in skin pigmentation between subsequent images. In order to solve this problem, the relative degree of erythema before and after laser treatment was computed in PWS lesion to normal skin (Figs. 4(a) and (b)). The selected normal skin sites were denoted by solid white lines in Fig. 4 and chosen at flat sites proximal to the PWS. Multiple normal skin regions were evaluated to reduce artifacts caused by vertical and horizontal patient movement offset. In the Fig. 4, E.I. of PWS lesion after laser treatment (Fig. 4(b)) were less than pre-treatment values (Fig. 4(a)) due to the expected PWS blanching in response to therapy. Such a positive treatment result was further confirmed using histogram presentation as shown in Fig. 5. In consecutive PWS treatments, the histogram will move to the lower relative E.I with less frequency if there is positive PWS clearing result. The average relative E.I values of before and after treatment were 63.7 and 52.7 % in the entire PWS lesion, respectively.

In the present study, PWS skin was imaged with a polarization spectral imaging system. The image analysis method allowed determination of erythema (E.I.) and melanin content (M.I.) and turned out to be an effective tool to document PWS blanching in response to laser therapy. Using our imaging system, a relatively large area was imaged in a noncontact fashion, which is an advantage over point measurement systems such as reflectance spectrophotometry and tristimulus colorimetry. In addition, problems associated with conventional digital images such as glare, shadowing, and nonuniform illumination, were minimized. Finally, the head positioning device can alleviate problems caused by variations in positioning, measurement distance, and camera angle.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Arnold and Mabel Beckman Fellows Program and National Institutes of Health (AR-43419 and AR-47551) for providing research grant support.

*Corresponding author : bjung@laser.bli.uci.edu.

REFERENCES

[1] J. S. Nelson, K. M. Kelly, Y. Zhao, Z. Chen, "Imaging blood flow in human port-wine stain in situ and in real time using optical doppler tomography," *Arch. Dermatol.*, vol. 137, no. 6, pp. 741-744, 2001.

[2] K. Onizuka, K. Tsuneda, Y. Shibata, M. Ito, I. Sekine, "Efficacy of flashlamp-pumped pulse dye laser for port wine stains: clinical assessment and histopathological characteristics," *Brit. J. Plast. Surg.*, vol. 48, no. 5, pp. 271-279, 1995.

[3] P. H. L. Koster, C. M. A. M. van der Horst, O. M. M. Bossuyt, M. J. C. van Gemert, "Prediction of portwine stain clearance and required number of flashlamp pumped dye laser treatments," *Lasers Surg. Med.*, vol. 29, pp. 151-155, 2001.

[4] S. Michel, M. Landthaler, U. Hohenleutner, "Recurrence of port-wine stains after treatment with the flashlamp-pumped pulsed dye laser," *Brit. J. Dermatol.*, vol. 143, no. 6, pp. 1230-1234, 2000.

[5] O. T. Tan, K. Sherwood, B. A. Gilchrest, "Treatment of children with port-wine stains using the flashlamp-pulsed tunable dye laser," *New Engl. J. Med.*, vol. 320, no. 7, pp. 416-421, 1989.

[6] M. Haederdsal, H. Efsen, M. Gniadecka, H. Fogh, J. Keiding, H.C. Wulf, "Changes in skin redness, pig-

mentation, echostructure, thickness, and surface contour after 1 pulsed dye laser treatment of port-wine stains in children," *Arch. Dermatol.*, vol. 134, no. 2, pp.175-181, 1998.

[7] M. J. C. van Gemert, J. S. Nelson, T. E. Milner, D. J. Smithies, W. Verkruysse, J. F. de Boer, G. W. Lucassen, D. M. Goodman, B. S. Tanenbaum, L. T. Norvang, L. O. Svaasand, "Noninvasive determination of port wine stain anatomy and physiology for optimal laser treatment strategies," *Phys. Med. Biol.*, vol. 42, no. 5, pp. 937-950, 1997.

[8] K. T. Le, J. Shahidullah, I. J. Frienden, "Review of modern techniques in detecting port-wine stain response to laser therapy," *Dermatol. Surg.*, vol. 25, no. 2, pp. 127-132, 1999.

[9] A. M. Troilius, B. Ljunggren, "Reflectance spectrophotometry in the objective assessment of dye laser-treated port-wine stains," *Brit. J. Dermatol.*, vol 132, no. 2, pp. 245-250, 1995.

[10] A. M. Troilius, B. Ljunggren, "Evaluation of port wine stains by Laser Doppler perfusion imaging and reflectance photometry before and after pulsed dye laser treatment," *Acta. Derm. Venereol.*, vol. 76, no. 4, pp. 291-294, 1996.

[11] E. Berardesca, P. Elsner, K-P Wilhelm, H.I. Maibach, *Bioengineering of the skin: Methods and Instrumentation* (CRC Press, Boca Raton, FL, 1995), pp. 29-40.

[12] M. D. Shriver, E. Parra, "Comparison of narrow-band reflectance spectroscopy and tristimulus colorimetry of measurements of skin and hair color in persons of different biological ancestry," *Am. J. Phys. Anthropol.*, vol. 112, no. 1, pp. 17-27, 2000.

[13] H. Takiwaki, S. Shirai, Y. Kanno, Y. Watanabe, S. Arase, "Quantification of erythema and pigmentation using a videomicroscope and computer," *Brit. J. Dermatol.*, vol. 131, no. 1, pp. 85-92, 1984.

[14] P. Clarys, K. Alewaeters, R. Lambrecht, A. O. Barel, "Skin color measurements: comparison between three instruments: the Chromameter, the DermaSpectrometer and the Mexameter," *Skin Res. Technol.*, vol. 6, no. 6, pp. 230-238, 2000.

[15] W. Alaluf, D. Atkins, K. Barrett, M. Blount, N. Carter, A. Heath, "The impact of epidermal melanin on objective measurements of human skin color," *Pigment Cell Res.*, vol. 15, no. 2, pp. 119-126, 2002.

[16] A. O. Barel, P. Clarys, K. Alewaeters, C. Duez, J. L. Hubinon, M. Mommaerts, "The Visi-Chroma VC-100: a new imaging colorimeter for dermatocosmetic research," *Skin Res. Technol.*, vol. 7, no. 1, pp. 24-31, 2001.

[17] H. Takiwaki, Y. Miyaoka, N. Skrebova, H. Kohno, S. Arase, "Skin reflectance-spectra and colour-value dependency on measuring-head aperture area in ordinary reflectance spectrophotometry and tristimulus colourimetry," *Skin Res. Technol.*, vol. 8, no. 2, pp. 94-97, 2002.

[18] J. K. Wagner, C. Jovel, H. L. Norton, E. J. Parra, M. D. Shirver, "Comparing quantitative measures of erythema, pigmentation and skin response using reflectometry," *Pigment Cell Res.*, vol 15, no. 5, pp. 379-384, 2002.

[19] H. Takiwaki, Y. Miyaoka, H. Kohno, S. Arase, "Graphic analysis of the relationship between skin colour change and variations in the amounts of melanin and hemoglobin," *Skin Res. Technol.*, vol. 8, no. 2, pp. 78-83, 2002.

[20] M. Seraro, A. Sparavigna, "Quantification of erythema using digital camera and computer-based image analysis: a multicentre study," *Skin Res. Technol.*, vol. 8, no. 2, pp. 84-88, 2002.

[21] S. A. Young-Gee, H. A. Kurwa, R. J. Barlow, "Objective assessment of port-wine stains following treatment with the 585nm pulsed dye laser," *Aust. J. Dermatol.*, vol. 42, no. 4, pp. 243-246, 2001.

[22] K. Miyamoto, H. Takiwaki, G. G. Hillebrand, S. Arase, "Utilization of a high-resolution digital imaging system for the objective and quantitative assessment of hyperpigmented spots on the face," *Skin Res. Technol.*, vol. 8, no. 2, pp. 73-77, 2002.

[23] D. K. Rah, S. H. Kim, K. H. Lee, B. Y. Park, D. W. Kim, "Objective evaluation of treatment effects on port-wine stains using L*a*b* color coordinate," *Plast. Reconstr. Surg.*, vol. 108, no. 4, pp. 842-847, 2001.

[24] B. L. Diffey, R. J. Oliver, P. M. Farr, "A portable instrument for quantifying erythema induced by ultraviolet radiation," *Brit. J. Dermatol.*, vol. 111, no. 6, pp. 663-672, 1984.

[25] P. M. Farr, B. L. Diffey, "Quantitative studies on cutaneous erythema induced by ultraviolet radiation," *Brit. J. Dermatol.*, vol. 111, no. 6, pp. 673-682, 1984.

[26] J. B. Dawson, D. J. Barker, D. J. Ellis, "A theoretical and experimental study of light absorption and scattering by *in vivo* skin," *Phys. Med. Biol.*, vol. 25, no. 4, pp. 695-709, 1980.