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A Quantitative Evaluation of Pigmented Skin Lesions Using the L*a*b* Color Coordinates

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Abstract

The evaluation of pigmentary skin lesions by clinical doctors has been based on subjective and qualitative judgements. Observations have mostly relied on visual inspection, making the effects of treatment difficult to evaluate with any precision. For this reason there is a real need for an objective method to evaluate prognosis after treatment. Recent scientific measurements such as reflectance spectrophotometry and reflectance colorimetry have provided accurate quantitative color information about skin lesions, but these techniques are costly and difficult to apply in the clinical field. The purpose of this study was to develop a simple and cost-effective way of evaluating treatment results. We have developed a software program using the L*a*b* color coordinate system to quantify the effect of treatment and have successfully demonstrated its clinical usefulness. Our method compares the relative color difference between normal skin and skin lesions before and after treatment, instead of measuring the absolute color of skin lesions. The accuracy of our quantitative color analysis was confirmed by the simulated images of hemangioma and ota nevus. Clinical efficacy was also confirmed through a blind test involving 3 clinicians who were asked to grade the treatment effects of 13 cases of hemangioma and 7 cases of ota nevus. These subjective clinical grades correlated well with the treatment results obtained using the proposed color analysis system (Correlation coefficient=0.84).

Key Words: Relative color difference, hemangioma, ota nevus, treatment effect

INTRODUCTION

While the color of human skin is an important parameter for clinical and scientific evaluations, subjective evaluation by visual observation lacks accuracy and objectiveness. The subjective evaluation of pigmentary lesions may lead to the following clinical problems:- Firstly, the evaluation does not provide an accurate prognosis of a skin lesion after various treatments; and secondly, the lack of a precise description of color information limits communication with others.[1-5] Although someone may be able to distinguish between several thousands shades of color, the descriptions for colors lack any reasonable precision, as there is no universal color term for every shade of a color.[1] To overcome such problems of color assessment, reflectance spectrometry or reflectance colorimetry has been utilized since they identify every color numerically.[4]

Kiyoshige used a quantitative evaluation of skin color after the replantation of a finger.[5] He demonstrated that skin color changes provide diagnostic information of post-microsurgical vascular insufficiency using a colorimeter. Weatherall made a quantitative analysis of skin color using the Comission Internationale d'Eclairage (CIE) L*a*b* color space parameters.[1] Mark et al. made an analysis of spreading skin erythema.[6] They evaluated the size of erythema through true color imaging using the L*a*b* color parameters. Pierard used standardized color parameters and a color analyzing instrument to eliminate the descriptive differences of clinicians and concluded that skin color and its changes could be precisely evaluated.[4]

The precise color analysis of lesions requires an expensive colorimeter or spectrophotometer and these methods usually measure the color of the skin sur-

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face.[1,4,5] Although these measurements allow accurate analysis, their high costs limit clinical application. Therefore, we have developed a method of providing a quantitative evaluation using pre- and post-treatment slide images.

MATERIALS AND METHODS

L*a*b* color coordinates

The perception of color in humans is achieved through the stimulation of the retina and optic nerves by electromagnetic radiation between the wavelengths of 400 and 700 nm, the so-called visible spectrum.[7] In 1802, Young proposed that the expression of any color was possible using the three basic colors.[8] There is an implication here that the three cone types are stimulated by some definition of the primary colors.[9] This fact encouraged the CIE to describe color space using R (Red), G (Green), and B (Blue) color parameters, but all colors could not be expressed using the CIE spectral primary color parameters. Therefore, the XYZ color space parameters were proposed using the positive tristimulus values.[7,9] The nature of human color vision has been quantified for the purpose of color measurement in terms of the 3 color matching functions, XYZ. The XYZ space parameters are related to R_{CIE} , G_{CIE}, and B_{CIE} as shown in equation (1).[6,9] The reference value of white is X=Y=Z=1.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R_{CIE} \\ G_{CIE} \\ B_{CIE} \end{bmatrix} \quad (1)$$

It was found to be difficult to relate the XYZ color space parameters to color perception because of the parameter's nonlinearity. To overcome this problem, a new parameter was proposed by the CIE in which the color space values enable colors to be regarded as existing in an approximately uniform three-dimensional space. Some of these new parameters are UVW (1964), U*V*W*, and L*a*b* parameters. The L*a*b* system is currently the most widely used for color analysis.[9,10]

The L*a*b* color coordinate system in Fig. 1 is composed of 3 coordinates; color lightness (L*) and 2 coordinates related to chromatic components (a* and b*). The a* coordinate represents the red-versus-green component and the b* coordinate represents the yellow-versus-blue component. Equation (2) represents the relationship between XYZ and the L*a*b* color values.[9]

$$\begin{aligned} L^* &= 25 \cdot \left(\frac{100 \cdot Y}{Y_0}\right)^{1/3} - 16, \quad 1 \le 100Y \le 100 \\ a^* &= 500 \cdot \left[\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right] \\ b^* &= 200 \cdot \left[\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right] \end{aligned} \quad (2)$$

X, Z: chrominance
Y: luminance
Xo, Yo, Zo: tristimulus values of the reference white
L*: lightness (100) − darkness (0)
a*: red (120) − green (−120)
b*: yellow (120) − blue (−120)

The L*a*b* space was constructed with respect to its conceptual relationship with the actual perception of color and it provides a means for measuring the difference between any 2 colors. The color difference can be calculated using coordinate geometry as the length of the line joining the respective color space coordinates as shown in equation (3).[7,9]

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (3)$$

Analysis of treatment effect using the L*a*b* color coordinates

The color perception depends upon the light source. To obtain an accurate color for photography, a standard white light source (D65) should be used to obtain properly reflected color.[11] However, since most slide films or photographs in the clinical settings are not taken under the same condition of illumination, it is almost impossible to acquire an absolute color difference. Therefore, it is difficult to accurately evaluate the effect of treatment by analyzing only the color difference of a skin lesion pre- and post-treatment. By comparing the color difference between the lesion and the normal skin pre- and post-treatment, problems arising from different illuminating conditions for photographs may be reduced.

Fig. 2 shows an example of the regions of interest (ROIs). Region A and B are normal skin and the lesion pre-treatment, and the region A' and B' are normal skin and the lesion post-treatment. The sum of RGB values for each region were determined and divided by the total area to obtain an average value, which was transformed into an L*a*b* value using equations (1) and (2). ΔE_{AB} and $\Delta E_{A'B'}$ in equations (4) and (5) are the color differences between the normal skin and the lesion pre- and post-treatment, respectively. The treatment effect was calculated using equation (6).

$$\Delta E_{AB}=[(L^*_A-L^*_B)^2+(a^*_A-a^*_B)^2+(b^*_A-b^*_B)^2]^{1/2} \quad (4)$$

$$\Delta E_{A'B'}=[(L^*_{A'}-L^*_{B'})2+(a^*_{A'}-a^*_{B'})2+(b^*_{A'}-b^*_{B'})^2]^{1/2} \quad (5)$$

$$\text{Treatment effect } (\%)=\left(1-\frac{\Delta E_{A'B'}}{\Delta E_{AB}}\right)\times 100 \quad (6)$$

From equation (6), a lesion improved by treatment would show a decreased color difference between the normal and abnormal ROIs, and thus the treatment effect would move towards 100%. In the case of no improvement, the effect would be 0%, because no difference in color was detected pre- and post-treatment. A software program has been developed using Microsoft Visual Basic 6.0 to perform the calculation.

Validation

To evaluate the accuracy of our color analysis system, hemangioma and ota nevus shown in Fig. 3 were simulated using Adobe Photoshop 5.0. The background (Red: 255, Green: 178, Blue: 150) was simulated to match the color of normal skin. Five ROIs were selected for the 2 simulated images.

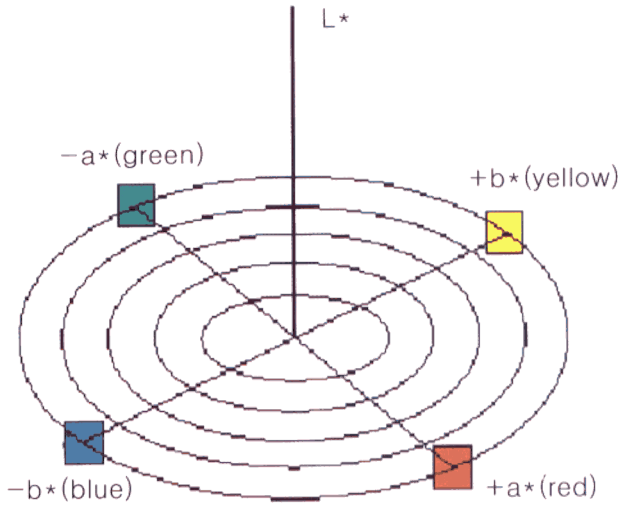

Fig. 1. CIELAB color coordinate system.[5]

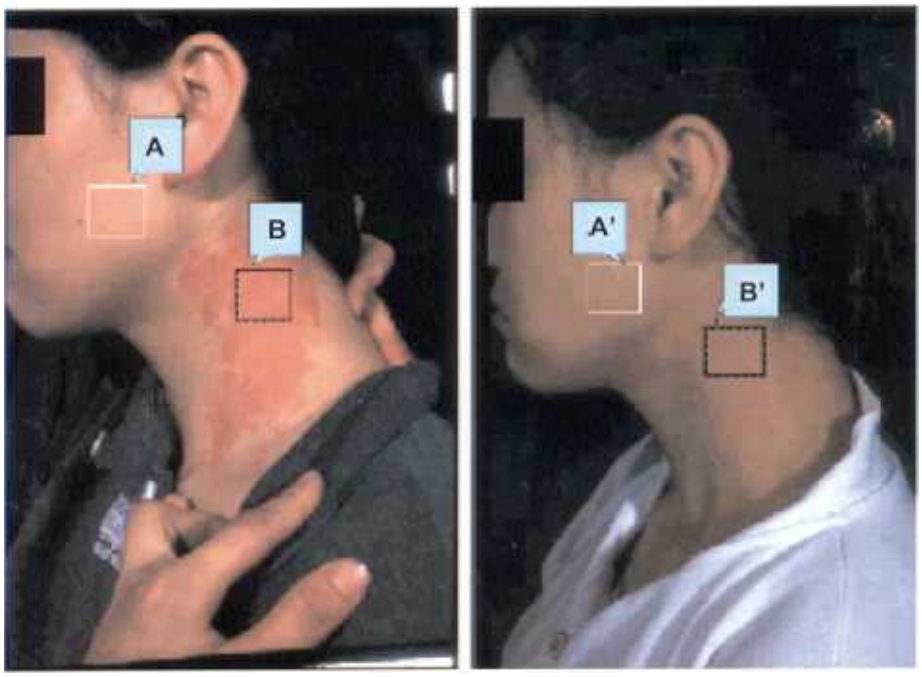

Fig. 2. An example of selected ROIs of normal skin (A, A') and lesion (B, B') for a hemangioma patient pre- and post-treatment.

To assess the clinical validity of our quantitative color analysis, the effects of treatment as determined by our method were compared to the subjective grades awarded by 3 clinicians. Three plastic surgeons were consulted to give their subjective grades on treatment efficacy by blind test. They were asked to grade treatment effects using 5% steps as shown in Table 1. The treatment effects ranged from 100%, the best result, to 0%, which indicated no effect. These subjective grades were compared to the effects of treatment obtained using our proposed method.

We analyzed images from a total of 20 patients representing 13 hemagioma and 7 ota nevus. All the pre- and post-treatment images of 20 patients were kept on positive slide films. A slide scanner (Nikon, LS-2000) was used to digitize the images and these were saved on a personal computer file.

RESULTS

Validation by simulation

Fig. 4 depicts a trend of L*a*b* differences of normal and simulated hemangioma and ota nevus images for each of the different ROIs in Fig. 3A and B. The x-axis represents the number of the ROI in Fig. 3 and the color differences between them decrease from left to right. The y-axis represents the L*a*b* color difference obtained by subtracting the L*a*b* values of the lesion from those of normal skin. The zero value of the y-axis indicates that there is no color difference. Fig. 4A represents the trend for simulated hemangioma and shows a relatively big difference in the a* value, which is influenced by the color red. As the ROI approaches the normal skin color, differences in the a* value decrease. Positive values of a* correspond to red and minus values to green, as shown in Fig. 1. Fig. 4B shows the trend of the L*a*b* difference for simulated ota nevus. It is greatly influenced by the color blue, represented by a negative b* value and it steadily approaches zero as the color difference becomes minimal.

To confirm whether a quantitative treatment effect can be accurately measured using color difference without the influence of color itself, treatment effect

Table 1. Subjective Grades Given by Clinicians

Grade (%)	Status
100, 95, 90, 85	Excellent
80, 75, 70, 65	Fair
60, 55, 50, 45	Good
40, 35, 30, 25	Poor
20, 15, 10, 5, 0	No response

Fig. 3. Simulated images for hemangioma (A) and ota nevus (B).

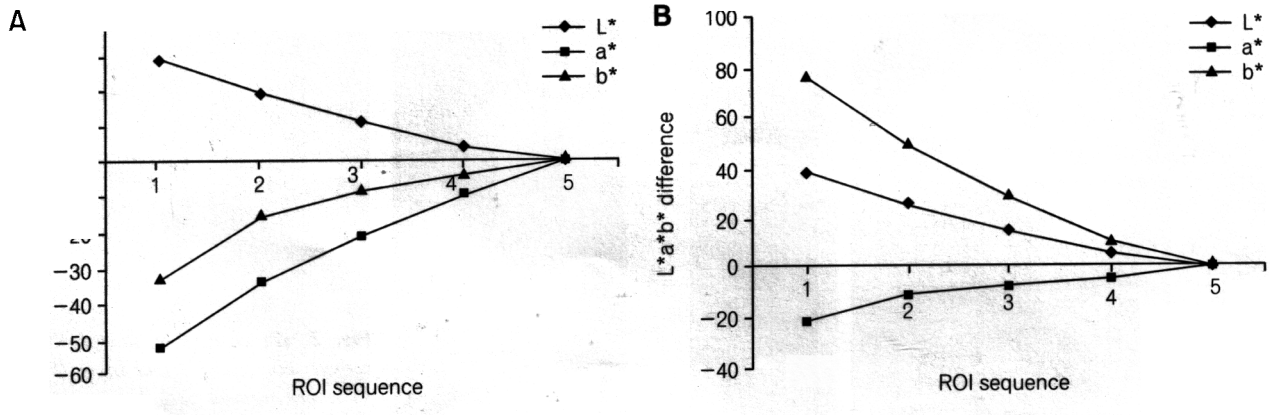

*Fig. 4. The L*a*b* differences of simulated hemangioma (A) and ota nevus images (B) for each ROI.*

was calculated for the 2 kinds of simulated images in Fig. 3 using equation (6). Fig. 5 shows that the treatment effects of hemangioma and ota nevus were accurately obtained and that they were not influenced by the colors themselves, as expected. The x-axis of Fig. 5 represents the ROI sequence and the y-axis the treatment effect.

Validation by clinicians

The hemangioma patient shown in Fig. 2 was analyzed, the result acquired by our color analysis software is shown in Fig. 6. The RGB and L*a*b* values for pre-treatment and post-treatment are shown on the left and right, respectively. The value in the lower left and right indicates the L*a*b* color difference between normal skin and skin lesion for the pre- and post-treatment slides, respectively. The L*a*b* color differences pre- and post-treatment were 23 and 4, respectively. The treatment effect as calculated by equation (6) was 83%, as is shown on the bottom left of Fig. 6. Fig. 7 shows an ota nevus patient (A) and the color analysis results (B).

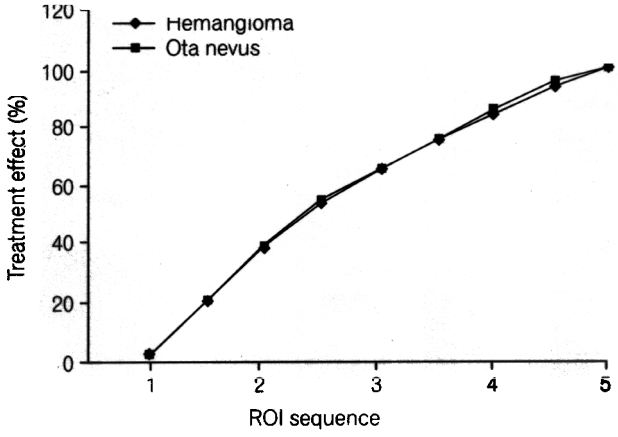

Fig. 5. The treatment effects obtained from images of stimulated hemangioma and ota nevus.

Fig. 8 represents the L*a*b* color differences pre- and post-treatment for 13 hemangioma and 7 ota nevus patients. The x-axis represents L*, a* and b*, and the y-axis represents the color difference of ROIs pre- and post-treatment. The ideal treatment would show no color difference and result in a y value of zero. Fig. 8A represents the mean and standard deviation of each L*, a* and b* color difference for 13 cases of hemangioma. The mean a* value, indicative of the red coloration, shows a marked decrease after treatment. The 7 cases of ota nevus as shown in Fig. 8B show a marked decrease of b* value, which represents blue.

The quantitative results from the color analysis were compared to the subjective assessment made by 3 clinicians by blind testing as is shown in Fig. 9.

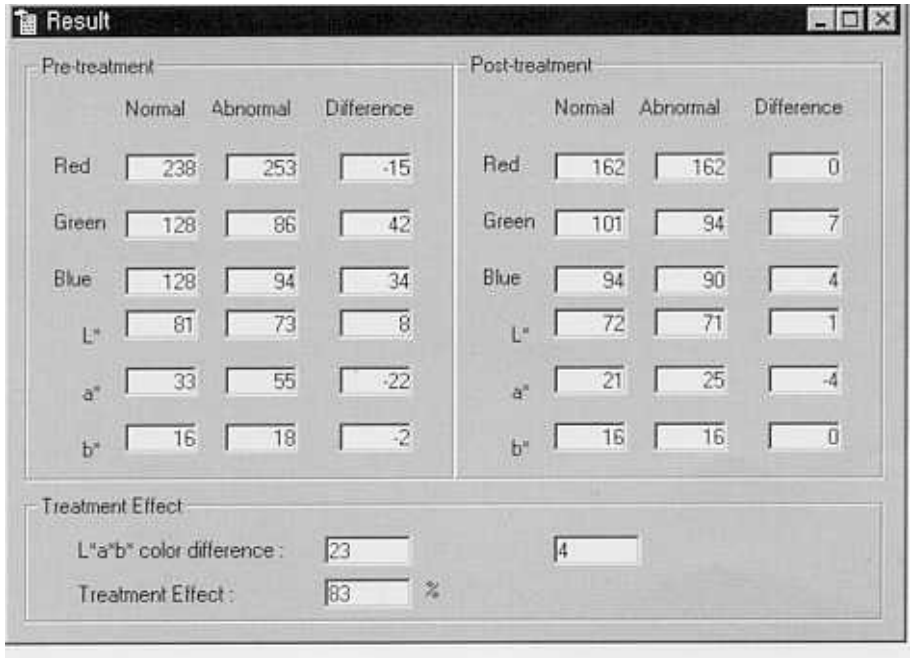

Fig. 6. The analysis results pre- and post-treatment of the hemangioma patient in Fig. 2.

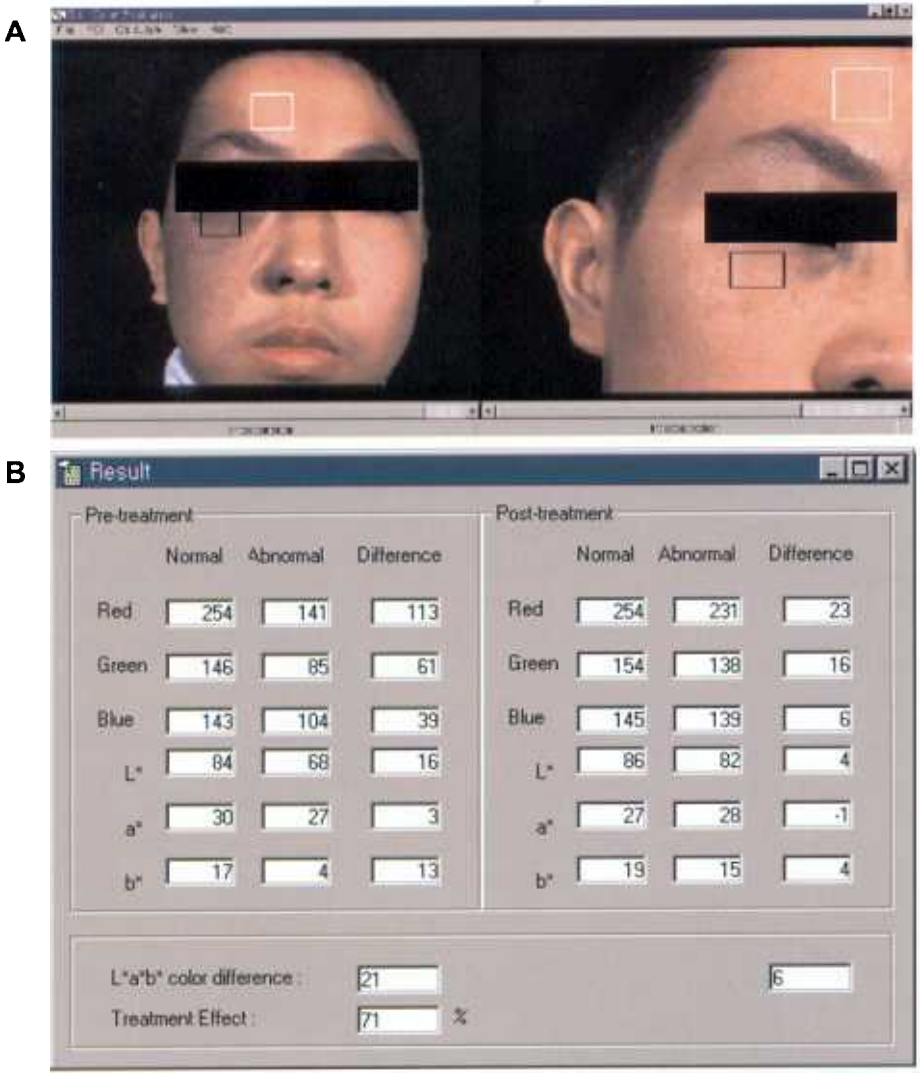

Fig. 7. (A) An example of selected ROIs of normal skin (white rectangle) and lesion (black rectangle) for ota nevus patient pre- and post-treatment. (B) The analysis results pre- and post-treatment.

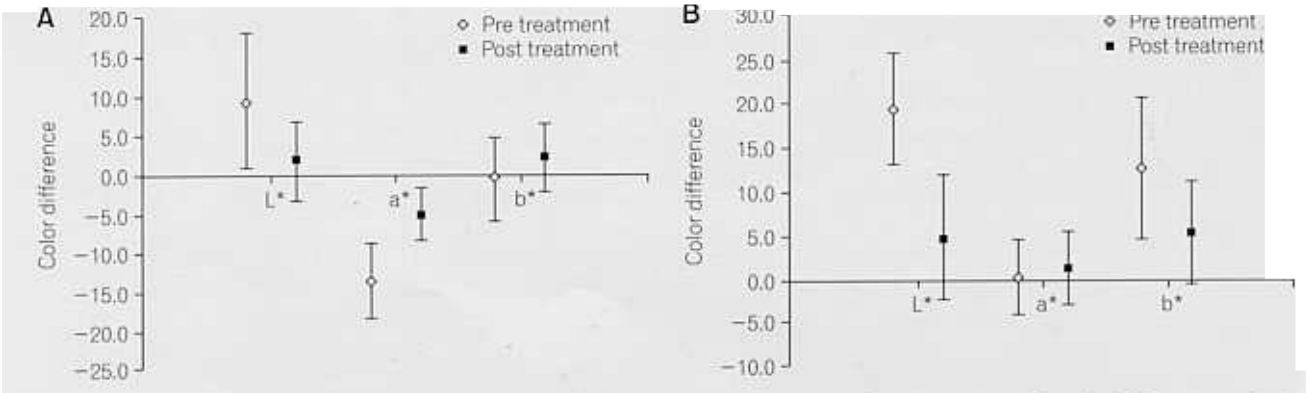

*Fig. 8. L*a*b* color differences pre-and post-treatment on 13 hemangioma (A) and 7 ota nevus patients (B). Each color difference was obtained by subtracting the value of the normal skin from that of the lesion.*

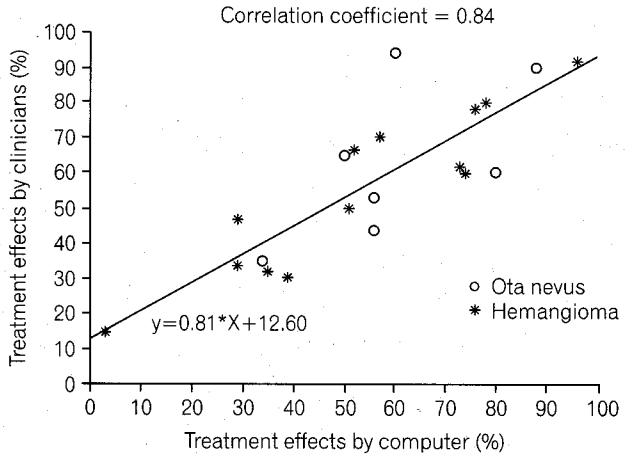

Fig. 9. Correlation of the treatment effects evaluated by our color analysis and by 3 clinicians.

The x-axis represents the treatment effect from color analysis and the y-axis the mean treatment effect as viewed by the 3 clinicians who were asked to grade the efficacy of the treatment in 5% increments from 0 to 100%. The correlation coefficient was 0.84, which is relatively high.

DISCUSSION

Treatment evaluation may be accurately performed by measuring the color differences of pigmentary lesions using a reflectance colorimeter or spectrophotometer. However, the units are expensive, and a selected ROI would be too small to cover the lesion if the lesion is relatively large and non-uniform in color. However, since our method uses an adjustable ROI area which accommodates the lesion size, and since mean color values are obtained, our method is more efficient than the absolute color measuring method, especially for larger-sized lesions. Another problem with the reflectance colorimeter and the spectrophotometer is that they can't evaluate treatment effects retrospectively. However, since most pre- and post-treatment photographs are kept in the form of slides, it is possible to evaluate treatment effects with our developed method.

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