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*Digital Camera Aids in Early Detection of Flap Ischemia**

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Abstract

Background: **Microvascular condition is the main factor in successful free-tissue transfer, which has gained increasing popularity during the past 20 years. Detection of early failure is of paramount importance for salvaging ischemic flap. Color is more frequently used as a clinical indicator in detecting flap ischemia. However, expertise is needed in detection the subtle change of color. By using digital camera, pictures taken serially can be analyzed by personal computer to compare the degree of color changes. With this hypothesis, we experimentally created an ischemic state in volunteers and correlated the differences of color with the disturbances of blood supply in digital camera pictures.**

Objectives: **To detect early change in color of tissue ischemic state by using digital camera.**

Materials and Methods: **A pneumatic tourniquet was applied to the left arm of 5 healthy colleagues with 250 mmHg pressure for 15 minutes. Two different digital cameras (Kodak DC 260 and Olympus Camedia C-2000) were used together simultaneously, in order to compare two studies at the same time. The photograph was taken serially every 5 minutes since the pressure was applied. The pictures were analyzed by Adobe Photoshop software to measure the skin color over their forearms in RGB and CMYK modes. Stata statistic program was used for data analysis. The values of the colors were plotted corresponding to the time intervals. The difference of color magnitude was calculated and analyzed.**

Results: **The preliminary study showed the differences in magnitude of color change at different time intervals. But statistic significance could not be measured due to the limited number of the samples. However, There is a trend that digital cameras can possibly detect subtle change of color in ischemic state though invisible to the human eyes.**

Conclusion: **Digital cameras may aid in predicting ischemic state. However, further studies in clinical trial are needed to conclude the results. Therefore, the method of measuring changes of colors with a digital camera will be applied to patients in Songklanagarind Hospital soon.**

Microvascular condition is the main factor in successful free-tissue transfer, which has gained increasing popularity during the past 20 years.[1-5] Early detection of failure is of paramount importance in salvaging the ischemic flap, especially during the first 36 hours post-operative.[6] Currently the most reliable detection method is intravascular oxygen tension; however, this takes time and well-trained technicians, and is also very expensive.[6-10] Many methods have been proposed and tried, but so far no reliable and easy alternative has been found.[11-14] Once ischemia has begun it is easily detectable by the color changes in the blood; however, considerable expertise is required to detect early changes, and the sharpness of human eyesight is different in each individuals.[7,8]

New advances in photogrpahy and computers may be applicable to this problem.

Materials and Methods+

A pneumatic tourniquet was applied to the left arms of 5 volunteers, with 250 mmHg pressure for 15

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+ *As this study involved human experimentation, approval was obtained from the Hospital Ethics Committee.*

minutes, in order to mimic the ischemic state of free flap. Two different cameras (Kodak® DC 260 and Olympus® Camedia C-200) were used simultaneously in order to compare the results. Photographs were taken serially of the left forearm every 5 minutes beginning from the application of the tourniquet. Lighting was standard operating room brightness, and the photographs were taken using the fixed focal length of each camera, 20 cm for Olympus®, and 30 cm for Kodak® which give the best performance for macro-mode for each camera (Figure 1). Photogrpahs were taken at 0, 5, 10, and 15 minutes, at which time the tourniquets were released.

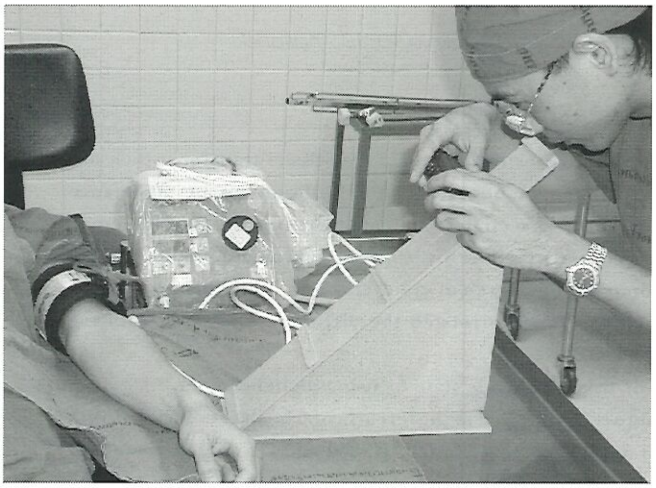

Fig. 1 Camera Arrangement

The photographs were then analyzed by the Adobe Photoshop® computer program to measure skin color and luminosity over the subjects' forearms in RGB and CMYK modes at beginning of our experiment. However, we subsequently learned that the RGB mode was most suitable for our studies (Figure 2). Color intensity was measured in luminosity-adjusted and unadjusted modes, to allow for possible effects from environmental light and validate the colour.

The Stata® v7 statistical program was used for data analysis by cross-sectional time-series, logistic regression. All data was compared within and between subjects.

Results

A difference in color magnitude is evident,

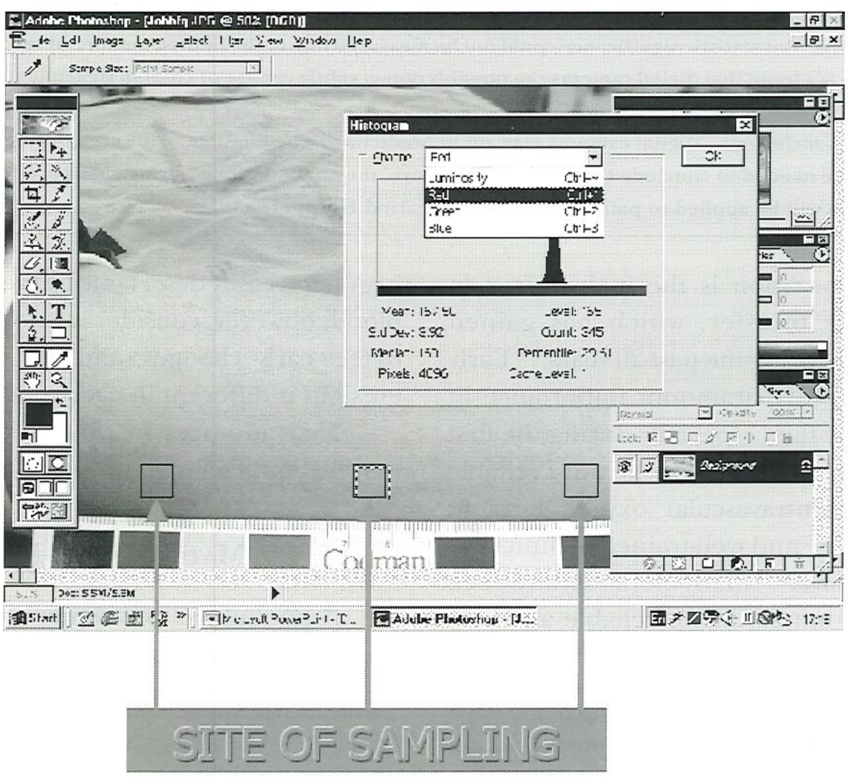

Fig. 2 Adobe Photoshop Color Measuring Program

Table 1 Luminosity-adjusted color values.

Adjusated value	Red				Green				Blue			
	t=0	t=5	t=10	t=15	t=0	t=5	t=10	t=15	t=0	t=5	t=10	t=15
Subject A												
Site I	165.45	170.35	168.81	166.82	142.69	144.17	142.68	138.51	125.53	118.09	116.75	111.97
Site I	157.06	156.76	153.42	154.00	133.29	128.94	125.45	124.15	118.39	106.51	103.65	101.06
Site III	144.75	150.42	146.97	144.15	119.50	121.84	118.23	113.11	107.90	101.12	98.16	92.67
Subject B												
Site I	160.20	153.82	155.16	155.49	136.55	133.90	131.10	131.17	120.39	106.54	115.65	116.44
Site II	164.42	158.35	158.06	160.39	141.28	138.97	134.35	136.66	124.06	110.47	118.16	120.69
Site III	145.22	140.93	138.58	139.37	119.79	119.47	112.53	113.13	107.40	95.35	101.26	102.45
Subject C												
Site I	205.46	200.42	200.28	202.35	179.41	170.87	176.53	171.83	152.69	145.21	148.80	143.21
Site II	205.41	203.36	202.28	204.91	179.36	173.79	178.52	174.37	152.65	147.65	150.46	145.33
Site III	187.54	193.02	185.96	186.25	161.64	163.53	162.34	155.87	137.84	139.08	136.93	129.86
Subject D												
Site I	176.39	160.62	158.68	169.48	142.23	133.02	130.66	136.66	115.03	110.97	110.54	111.47
Site II	169.86	159.75	151.38	161.61	135.77	132.15	123.45	128.89	109.10	110.18	103.92	104.34
Site III	136.28	122.11	115.32	126.20	102.61	94.98	87.83	93.91	78.65	76.04	71.21	72.22
Subject E												
Site I	158.73	150.26	152.35	133.83	124.36	116.64	118.14	105.25	94.85	92.61	96.53	84.82
Site II	151.22	144.04	141.63	143.64	117.94	111.33	108.99	113.63	90.06	88.65	89.71	91.06
Site III	136.51	110.57	106.37	104.68	105.38	82.73	78.86	80.35	80.70	67.34	67.26	66.27

t_0 = *time at beginning of tourniquet application*
t_5 = *time at 5 minutes after tourniquet application*
t_{10} = *time at 10 minutes after tourniquet application*
t_{15} = *time at 15 minutes after tourniquet application*

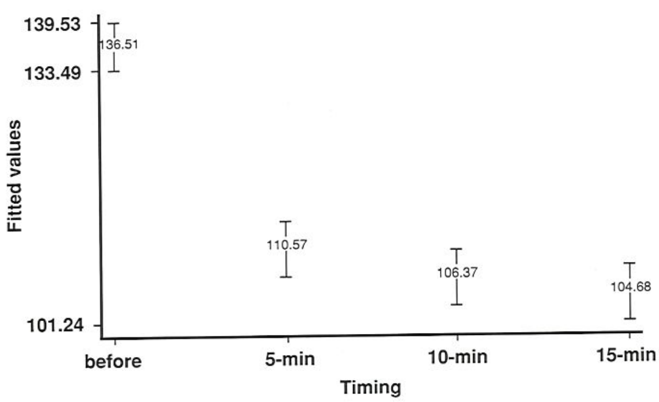

Fig. 3 Changing color values at ischemia site as detected by computer analysis of digital images.

although the number of sample is too small to detect statistical significance. Color intensities over time in each individual are shown in Table 1. Color data were plotted against time (Figure 3). Difference in color magnitude is shown in Table 2. The trend observed indicates that the digital camera can detect subtle color changes which indicate a potential ischemic state that are undetectable to the human eye at the stage. The probability of flap ischemia tended to vary inversely with color intensity, which will assist in determining whether the falp was progressively becoming ischemic or not (Table 3). Analysis of other colors also indicated that different channels may be available for early detection (Figures 4, 5).

The base skin color of each participating individual was different, but it did not effect tissue-color monitoring. In subject D skin mottling appearance was observed in a brief period after tourniquet application. This effect was not seen in other subjects. However, analysis of Red luminosity-adjusted color value in subject D also showed a discordant pattern. The significance of this discordant observation was not apparent in this limited study. Also, intra-individual analysis of color change did not reveal any difference in the color-change trend.

Discussion

Although microvascular surgery has been

Table 2 Accumulative chages in color values.

	Red			Green			Blue		
	t_5-t_0	t_{10}-t_0	t_{15}-t_0	t_5-t_0	t_{10}-t_0	t_{15}-t_0	t_5-t_0	t_{10}-t_0	t_{15}-t_0
Subject A									
Site I	4.902	3.335	1.365	1.480	-0.007	-4.183	-7.441	-8.784	-13.559
Site II	-0.304	-3.638	-3.063	-4.352	-7.840	-9.142	-11.874	-14.738	-17.328
Site III	5.672	2.224	-0.602	2.342	-1.273	-6.386	-6.785	-9.747	-15.233
Subject B									
Site I	-6.379	-5.031	-4.702	-2.648	-5.450	-5.376	-13.857	-4.747	-3.956
Site II	-6.076	-6.357	-4.029	-2.308	-6.936	-4.623	-13.594	-5.898	-3.372
Site III	-4.295	-6.642	-5.849	-0.314	-7.254	-6.660	-12.048	-6.145	-4.951
Subject C									
Site I	-5.033	-5.179	-3.110	-8.538	-2.880	-7.581	-7.480	-3.896	-9.485
Site II	-2.041	-3.127	-0.497	-5.572	-0.845	-4.989	-4.999	-2.195	-7.318
Site III	5.484	-1.575	-1.293	1.890	0.694	-5.779	1.239	-0.900	-7.978
Subject D									
Site I	-15.770	-17.713	-6.913	-9.210	-11.569	-5.569	-4.051	-4.487	-3.553
Site II	-10.109	18.477	-8.247	-3.619	-12.324	-6.886	1.083	-5.180	-4.763
Site III	-14.171	-20.691	-10.080	-7.631	-14.777	-8.696	-2.602	-7.433	-6.425
Subject E									
Site I	-8.469	-6.388	-24.905	-7.716	-6.218	-19.113	-2.240	1.682	-10.031
Site II	-7.174	-9.586	-7.577	-6.609	-8.950	-4.311	-1.416	-0.353	0.998
Site III	-25.946	-30.146	-31.828	-22.645	-26.512	-25.026	-13.364	-13.439	-14.437

Table 3 Statistical representation of observed and measured color value changes.

Prediction of ischemic state	Conditional Fixed-effects logic Group variable: subject			Odds Ratio (95% confidence interval)	P-value
	No. of subjects	No. of Observations	LR×12		
Red	5	60	3.44 (p=0.0635)	0.9549 (0.9037-1.0089)	0.100
Green	5	60	3.32 (p=0.0686)	0.9547 (0.9033 - 1.0091)	0.101
Blue	5	60	4.49 (p=0.0341)	0.9370 (0.8749-1.0034)	0.063

LR ×12 = Logistic Regression of 12 samples.

progressively developed, the most important factor that affect outcome is post-operative monitoring. Laser Doppler plethysmography is accepted as the most accurate measurement in monitoring tissue blood supply following surgery. But it is not practical for everyday use in every hospital where microvascular surgery is being frequently performed. The best solution is to search for newer method that can predict accurately tissue viability and yet more convenient and less expensive. In our hypothesis, we did not intend to create new technique to replace the already known "gold standard" but rather to find another way to accomplish the same outcome with ease of clinical application.

The visual color appearances are usually used in clinical practice to observe viability of the free tissue

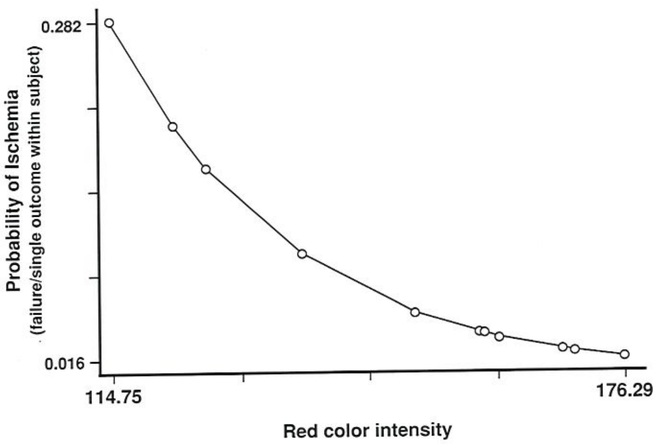

Fig. 4 Correlation of color change with probability of tissue failure.

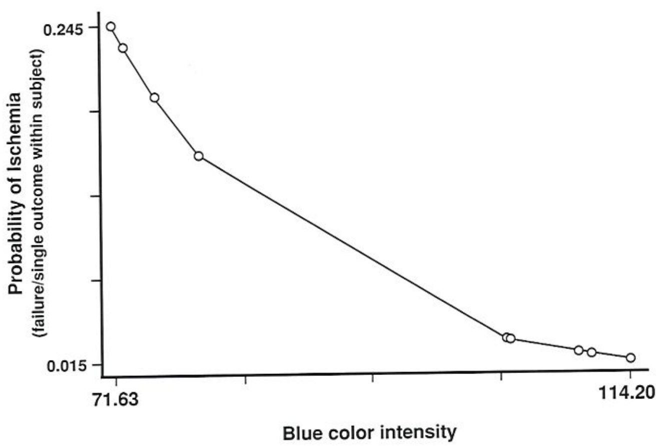

Fig. 5 Correlation of color change with probability of tissue failure.

transfer. Digital camera has higher capability to record and assess color appearances than visual observation. Thus, it could be a good device method to assist in predicting free tissue transfer viability in clinical setting. We found no prior report of this application technique, so we have to develop the technique of our own. From the fact that ambient light might have effect upon color perception, we began our experiment by taking photograph in different light source of different intensity. We found no interference from the ambient light on color recording by digital camera. Thus, the use of digital camera for our purpose would require no environmental control.

In our experiment, the volunteer's arm was used to represent the vascularized flap. After the tourniquet was applied, ischemic process began. Serial photographs were taken to compare color intensity in each subject. The results were considered both individually and grouped. The different color channels were used to adjust and confirm the hypothesis that Red and Blue color can reflect the status of tissue perfusion. We started our measurement in RGB (Red, Green, Blue) and CMYK (Cyan, Magenta, Yellow, and Kerr) mode; CMYK mode is usually used in printing and multimedia work. But we finally found that RGB is the most suitable mode to use in our experiment.

The Red channel was used in order to detect arterial blood flow in the tissue. If our hypothesis is correct, the Red color intensity should be diminishing as the tourniquet was being applied.

In the same way, the result should be in the reverse with Blue channel. We found only one discordant result in subject D on the Red channel. The significance of this observation should be determined in future studies. But the results in other channels were normal as expected. We think this might be caused by some yet unknown factor in photographing and/or analysis.

From the group analysis, we found no significant difference in color intensity serially obtained. But there was an observable potential trend in predicting the possibility of ischemic process in tissue of each individual. We believe our method may be able to predict the free-flap ischemia correctly on clinical application setting if we can improve the method of color analysis. There is an ongoing experimental study in our institute in revascularized tissue viability monitoring, and we hope to report the results of this experiment in the near future.

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