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Photometric measurement of pressure-induced blanching of livor mortis as an aid to estimating time of death

Application of a new system for quantifying pressure-induced blanching in lividity

H.-J. Kaatsch, E. Schmidtke, W. Nietsch

Institut für Rechtsmedizin, Christian-Albrechts-Universität zu Kiel, Arnold-Heller-Strasse 12, D-24105 Kiel, Germany

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Summary. A newly developed digital system employs photometric measurement of pressure-induced blanching of livor mortis to estimate time of death. The conventional method of applying pressure with thumb or forceps relies largely on subjective interpretation. Our system improves on this method by photometric quantification of color changes produced by defined magnitudes of pressure. We tested the new system by applying increasing levels of pressure to lividity in 50 cadavers with known time of death. Characteristic courses for pressure-induced changes were found for the brightness component of livor mortis, revealing distinct differences between the respective postmortem intervals. The surface areas under these curves were then calculated and distributed into 10-hour postmortem time categories. Variance analysis of these surface values revealed clear differences between the time categories, especially in the medians. Distinct differences between the various postmortem time categories were also evident for the chroma component of livor mortis. The new system offers a further method – in addition to body temperature, rigor mortis, and the electrical responsiveness of skeletal muscles – for estimating time of death, especially after long postmortem intervals.

Key words: Livor mortis – Blanching – Photometry – Dynamometry –Estimation of time of death

Zusammenfassung. Ein neu entwickeltes Meßgerät erfaßt kraft- und farbmetrisch die Wegdrückbarkeit von Totenflecken und ersetzt die bisherige subjektive Methode, die Abblassung von livores auf Daumen- oder Pinzettendruck zu beurteilen. Die Farbänderung der Totenflecke wird computergesteuert bei definiert ansteigendem Druck gemessen und in Relation zur jeweiligen Druckstärke ausgewertet. Bei der Untersuchung der Wegdrückbarkeit an 50 Leichen zeigten sich charakteristische Kurvenverläufe der druckbedingten Veränderung der Helligkeitsanteile in der Farbe von livores für verschiedene postmortale Intervalle. Errechnet man die Flächen unter diesen Helligkeits-Verlaufskurven und faßt diese in Zeitklassen p.m. (10-Stunden-Intervalle) zusammen, ergibt die Varianzanalyse Unterschiede der Meßwerte – vor allem des Medians – zwischen den einzelnen Zeitklassen. Auch bei den Buntheitsanteilen in der Farbe von Totenflecken sind die Meßergebnisse für verschiedene Zeitklassen voneinander abgrenzbar. Die neue Methode objektiviert das Verhalten von livores auf Druck anhand der Quantifizierung physikalischer Meßgrößen und ergänzt die bestehenden Methoden zur Todeszeitbestimmung. Darüberhinaus eröffnet das Meßsystem neue Ansätze der Todeszeitschätzung für länger zurückliegende Todeszeitpunkte, bei denen die Messung des Temperaturabfalls, bzw. der elektrischen Erregbarkeit der Muskulatur weniger zum Tragen kommt.

Schlüsselwörter: Totenflecke, Wegdrückbarkeit – Totenflecke, Farbmessung – Totenflecke, Druckmessung – Todeszeitschätzung

Correspondence to: H.-J. Kaatsch

Introduction

Livor mortis is a definitive sign of death caused by the accumulation of blood, which is no longer circulating, in the vessels of the skin [4, 17, 22]. Livor mortis is one of several factors, including body temperature, rigor mortis, and the electrical responsiveness of skeletal muscles, applied in forensic practice to estimate the time of death [6, 9, 11–13]. Until now assessment of the blanching produced by applying pressure with thumb or forceps to livor mortis has relied largely on subjective impressions, i.e. on whether the pressure produced visible blanching [14–16, 19]. This relatively primitive method has long been in need of replacement by quantitative methods. Quantitative techniques have already been applied in varying degrees by Bakulev [1], Fechner et al. [5], v. Hunnius et al. [8] and Schuller et al. [20, 21] in the study of pressure-induced blanching of livor mortis. Vanezis evaluated the redistribution of hypostasis by measuring the blanching produced by turning the supine cadaver into the prone position [23].

We have developed a computer-aided system for the photometric measurement of blanching in livor mortis as a function of pressure and time [10]. The present paper reports on the results of initial tests applying the new system in a series of 50 cadavers with known time of death.

Materials and methods

Measurements were performed on 50 cadavers with known time of death[1]. No selection was made according to the presumed cause of death except in cases of exsanguination, high blood loss, or blood disease. Bodies received immediately after death were stored at +12° to +15°C. In 3 instances the bodies had been stored at +4/5°C for up to 12 hours prior to measurement. In some cases, the body was exposed to unknown environmental temperatures during the interval between death and storage. Measurements were carried out at a temperature of +12° to +15°C. In most instances measurements began within the first 10h p.m. and continued up to 40h p.m. In a few cases they did not begin until the second day postmortem.

The digital measuring system has been described elsewhere [10]. A special measuring head housing a photometric device and dynamometer was applied through precut openings in a table to standardized sites on the dorsal thorax and lumbar region. In the first bodies, measurements were made by pressing the measuring head by hand up against the dorsal skin surface. In this manner a maximum pressure of 80 newtons (N) could be attained. The procedure was then standardized by means of a screw device that moved the measuring head upward against the skin at a steady rate, automatically triggering photometric measurements in 10N increments every 5 seconds, beginning at 0N (starting value) and continuing up to 100N (maximum value). Measurements were performed on 36 cadavers in this manner.

The photometric measurement of color changes was carried out by means of the L, a*, b* system [CIE-LAB according to DIN 5033 (2), DIN 6174 (3)] for the geometric depiction of subtle differences in color spacings (Fig. 1). In the L*, a*, b* system, the L* (brightness) value specifies the position on the vertical light-dark axis (white=100, black=0), the a* value specifies the position on the red-green axis (+a*=red, –a*=green), and the b* value specifies the position on the blue-yellow axis. The CIE-LAB color system also employs a color difference value ΔE* (DIN 6174) that encompasses all color differences in a single arithmetic value [3]. ΔE* expresses color differences always in relation to a base (reference) value. The chroma component (C*) is calculated from the a* and b* values, where $C^* = \sqrt{a^{*2} + b^{*2}}$.

A total of 5000 measurements were made on the 50 cadavers. The 3 color components of the L*, a*, b* system were registered by the color difference measuring instrument and the resulting color difference value ΔE* was then calculated according to a color difference formula. This produced approximately 20,000 values for analysis. Once the standard of 100N had been established, nearly 4000 measurements on 36 cadavers were analyzed by means of a program developed specially for this purpose. These results were subjected to a variance analysis and depicted graphically using the "Box-and-Whisker Plot"[2].

Variance analysis was done by distributing the color value measurements into 5 postmortem time categories of 10 hours each (0–10, 10–20, 20–30, 30–40 and 40–50h p.m.). The "Box-and-Whisker Plot" distributed the data for each time category into 4 quartiles. In the Box-and-Whisker Plot, the "box" depicts the middle 50% and the "whiskers" (vertical lines) indicate the 95% confidence range. The median is shown by the horizontal line in the boxes (cf. Fig. 6). Since the data were distributed asymmetrically within the boxes for the respective postmortem intervals, the median was used to depict the general tendency of the changes. Hence, the movement of a box up or down depicts the shift in the middle 50% of all measured values in that time category. The notches in the boxes represent the 95% confidence range for the median: a significant difference between 2 medians is indicated when the notches of 2 boxes do not overlap (cf. the first 3 time categories in Fig. 6).

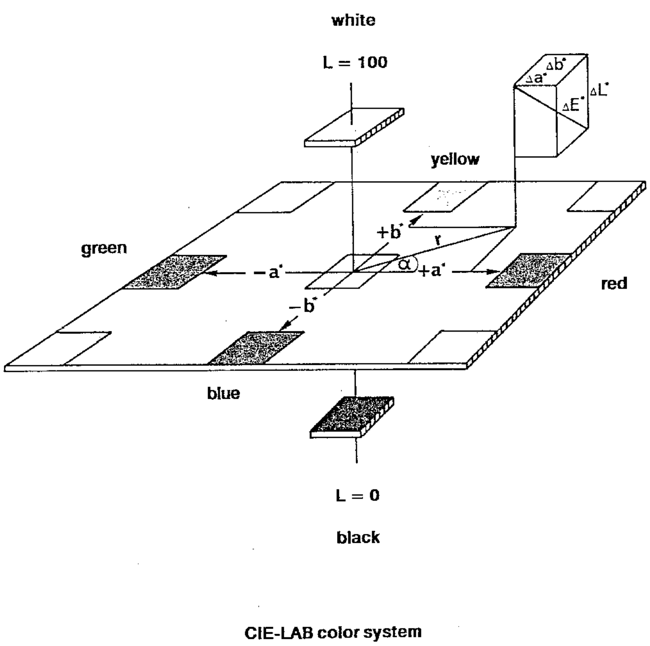

Fig. 1. CIE-LAB color system

Results

*Analysis of the color difference value ΔE**

Since the single color difference value ΔE* encompasses all 3 L*, a*, b* color values, we began by calculating the ΔE* values. Figures 2 and 3 reveal a characteristic clus-

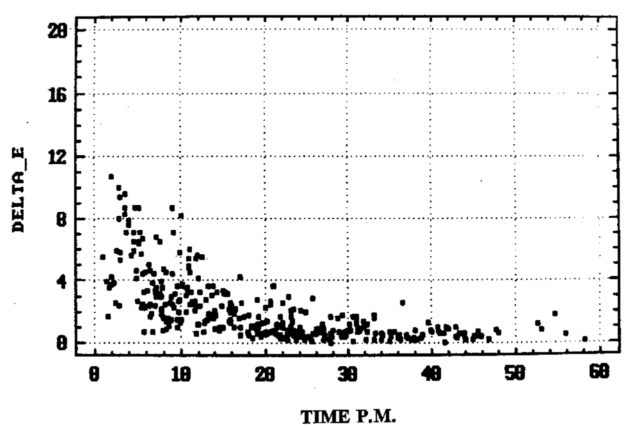

Fig. 2. Color difference values (ΔE*) at 20N (n=36). Note the marked color changes in the early postmortem interval

[1] We are grateful to Prof. Dr. K. Püschel for allowing us to carry out some of the measurements at the Institute for Forensic Medicine of the University of Hamburg

[2] STATGRAPHICS", version 5.0

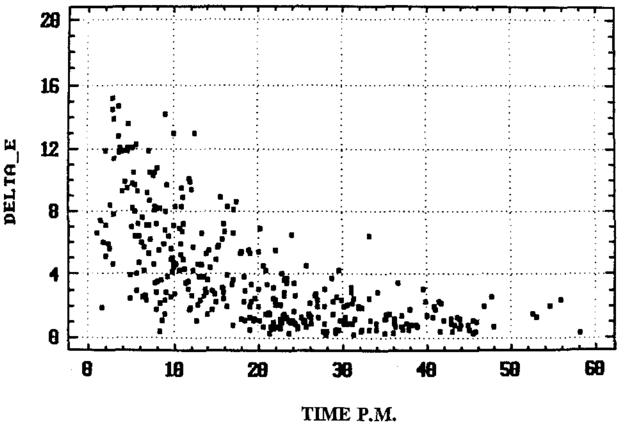

Fig. 3. Color difference values (ΔE*) at 60N (n=36). 60N produce clearly greater differences than 20N (cf. Fig. 2)

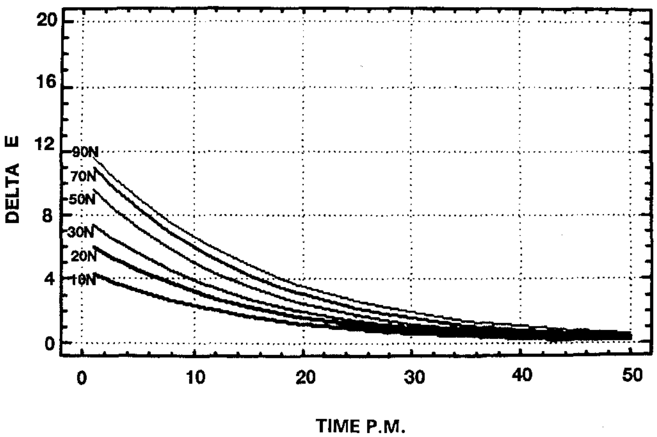

Fig. 4. Regression curves for ΔE* values at 10N–90N in a single case

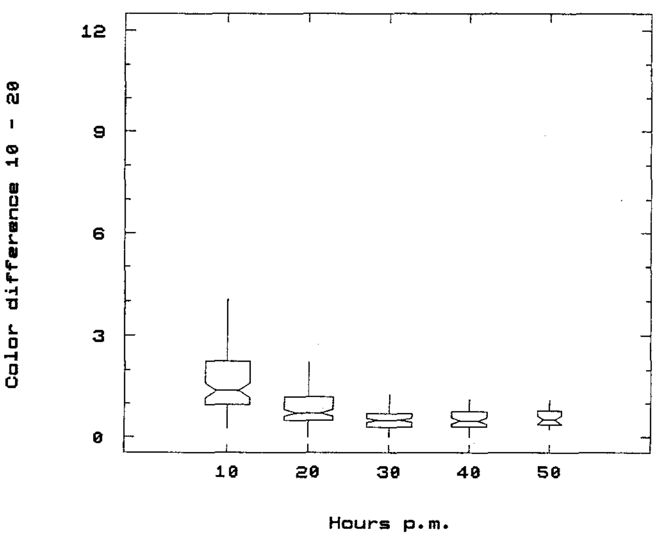

Fig. 5. Color difference values (ΔE*) produced by increasing pressure from 10N–20N (n=36; Box-and-Whisker Plot)

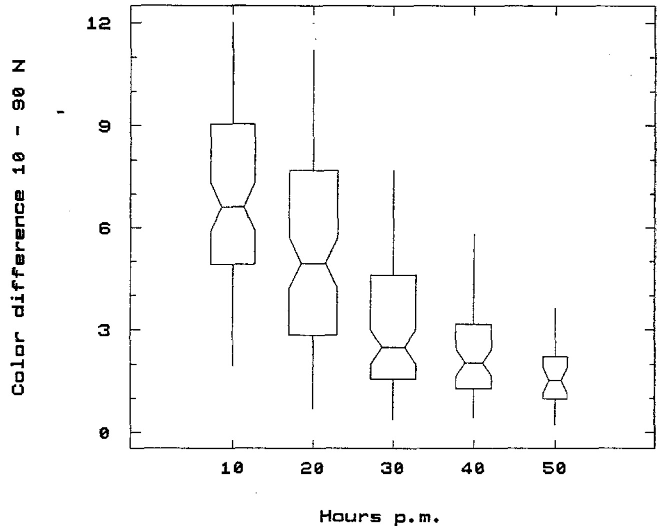

Fig. 6. Color difference values (ΔE*) produced by increasing pressure from 10N–90N (n=36; Box-and-Whisker Plot)

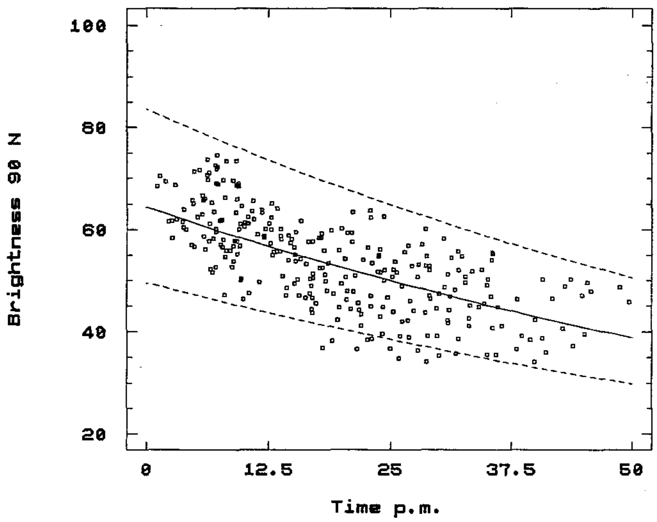

Fig. 7. Brightness values at 90N up to 50h p.m. (n=36). Brightness values show a steady decline with increasing postmortem interval

tering of points as a function of pressure (at 20N and 60 N, respectively). We tested the dependence of ΔE* values on the postmortem interval in single cases. Exponential regression analysis of the ΔE* values for the different pressure levels in a single case revealed a correlation coefficient of –0.8 for each level (Fig. 4). For the group of 36 cadavers, the vast color differences (especially pronounced at high pressures) were depicted by means of the Box-and-Whisker Plot. The dynamics of blanching were clearly less evident at slight increases of pressure (from 10N–20N; Fig. 5) than at large increases (from 10N–90 N; Fig. 6), especially in the early postmortem intervals.

Analysis of L, a, *b* values at 90N*

Pressure-induced changes in L*, a*, b* values in livor mortis were analyzed at 90N. The longer the postmortem

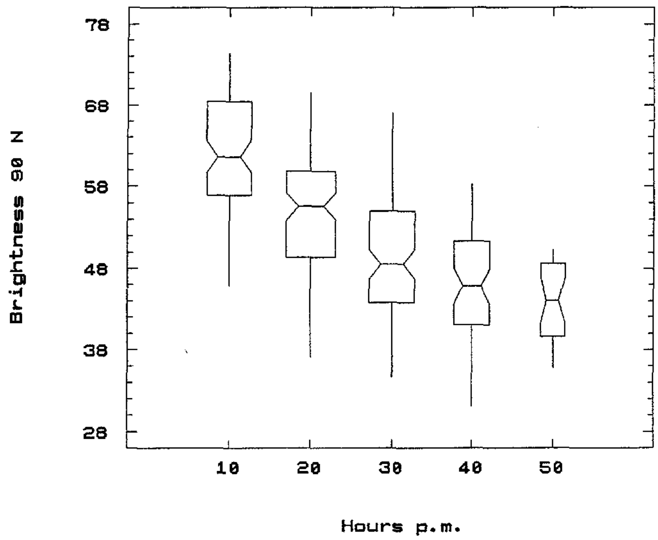

Fig. 8. Brightness values at 90N (Box-and-Whisker Plot) (n=36). Variance analysis of the data in Fig. 7 using the Box-and-Whisker Plot

interval, the lower the L* values, even before application of pressure. Applying 90N of pressure produced an additional "darkening" of the livor mortis (Fig. 7). The decline in brightness and in the medians was most pronounced in the first 3 time categories (Fig. 8). The a* values revealed an increase in the red component with time at 90N. The red component peaked between 30 and 40h p.m and changed little thereafter. The b* values, like the brightness values, showed a general decline which was most pronounced in the first 3 time categories.

Analysis of changes in brightness (L) values*

Characterization of brightness changes under increasing pressure. The greatest changes in the L*, a*, b* values under increasing pressure occurred in the L* values. Figure 9 exhibits typical courses for changes in brightness under increasing pressure as measured at specific postmortem intervals. In the early postmortem period a steep (nonlinear) climb was evident, corresponding to an increase in brightness. From 5 to 15h p.m. a more gradual upward (linear) course was followed. Between 15 and 30h p.m. the course was still slightly positive. Beginning at about 30h p.m. the course declined, reflecting a visible "darkening" of the livor mortis.

Brightness changes calculated as surfaces areas. In order to register each course numerically, we calculated the surface areas beneath the plotted lines and checked their correlation with the postmortem interval. In Fig. 10 the surface areas of all curves (n=36) are depicted according to the length of postmortem interval. The horizontal line represents a surface area of 0. The middle 50% ("boxes") of all surface areas showed a continual decline in the first 3 time categories, the medians differed significantly up to 30h p.m. Up to 20h p.m. most surface areas lay above 0, as calculated from curves with an increase in brightness. After 40h p.m. the surface areas were almost exclusively negative.

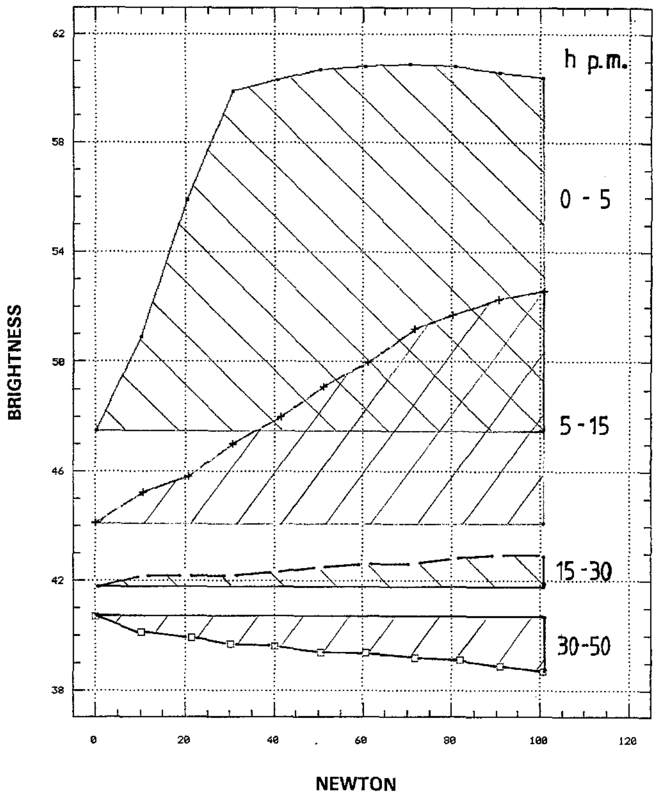

Fig. 9. Characterization of the brightness courses under increasing pressure; typical courses at 4 different postmortem intervals

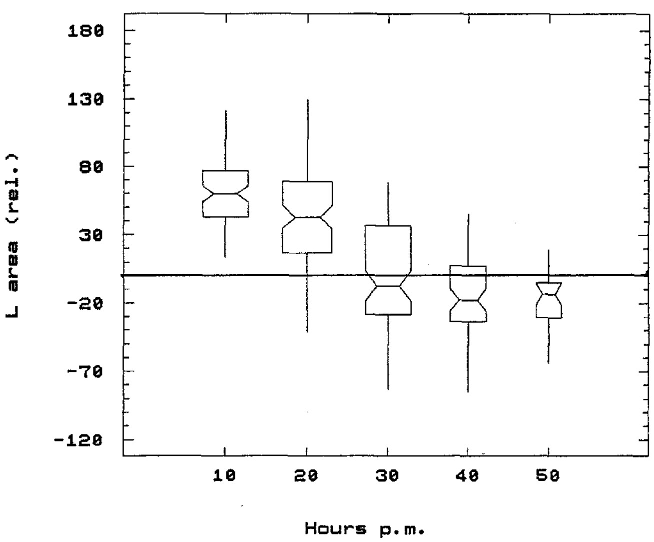

Fig. 10. Surface areas for brightness curves (n=36; Box-and-Whisker Plot)

Analysis of the chroma and brightness components. Pressure applied to livor mortis produced changes not only in brightness but also in the C* values, which are largely independent of brightness (10, 18). We calculated the product of the C* and the L* values at 90N for the defined postmortem time categories. The median for the individual categories differed significantly up to 40h p.m. (Fig.

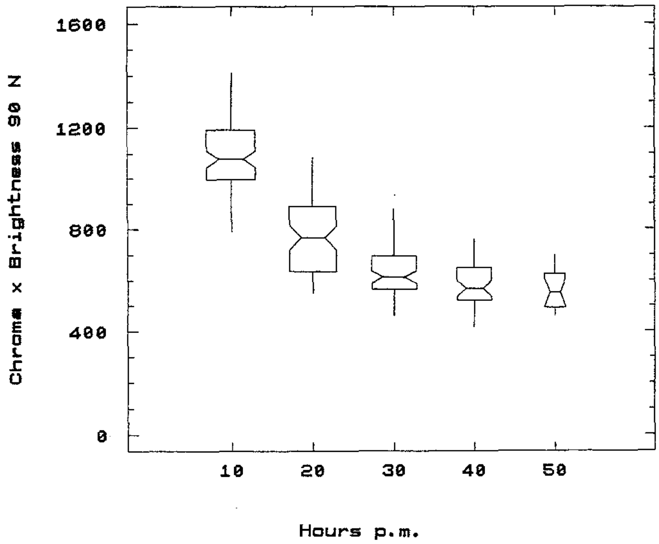

Fig. 11. Product of brightness and chroma components at 90N. Variance analysis using the Box-and-Whisker Plot

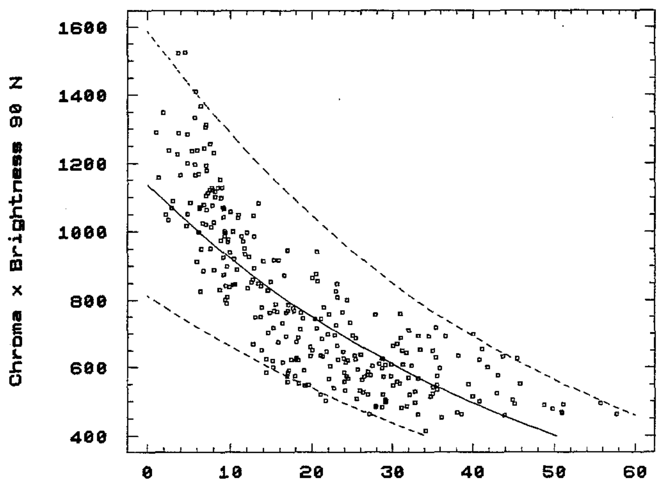

Fig. 12. Product of brightness and chroma components at 90N. Exponential regression analysis, r=–0.82

11). The middle 50% of the measured values varied most markedly in the first 2 time categories. The differences between 0 and 10h p.m. and between 10 and 20h p.m. were much more evident here than in the corresponding surface areas for brightness alone (cf. Fig. 10). Exponential regression analysis revealed a correlation coefficient of 0.82 (Fig. 12).

Discussion

The measurement system presented here uses photometric analysis of pressure-induced blanching in livor mortis as a means of estimating time of death. Measurements revealed regular courses in the pressure-induced color changes in livor mortis with time.

The following conclusions can be drawn from our initial investigations:

1) A system combining photometry and dynamometry to measure pressure-induced blanching of livor mortis is superior to the conventional method.

2) Pressure-induced color changes in lividity can be divided into a brightness, a red, and a yellow component as specified by the L*, a*, b* system. The individual color components can be graphically depicted in relation to increases in pressure from 0N–100N; an additional parameter is the color difference value ΔE*, which encompasses all color differences in a single arithmetic value.

3) Our unselected material, which closely approximates material encountered in forensic practice, showed typical postmortem changes in the pressure-induced blanching of livor mortis that should also reflect routine findings. Although digital analysis of the measured values could be performed on only 36 of the 50 cadavers, the findings in the remaining 14 cases were comparable. Hence, our conclusions can be said to apply to the entire group. The use of a combination of independent quantitative factors (differences in pressure, changes in brightness and hue) enables the objective measurement of pressure-induced blanching of livor mortis and thus represents an advance over the subjective evaluation of the blanching produced by applying pressure with the thumb or forceps.

Applying our photometric criteria, we achieved the following results:

a. Individual curves for ΔE* values (the color changes produced by increasing pressure) showed a clear exponential decrease with time. Comparison of color changes produced by increasing pressure from 10N–20N with those produced by an increase from 10N–90N revealed possibilities for distinguishing between different postmortem intervals. Similar differences are evident in changes in brightness produced by an increase from 10 N–20N as compared with those produced by an increase from 80N–90N.

b. The brightness component (L*) exhibited regular courses under increasing pressure. Evaluation of curves on the basis of objective parameters, such as angle of increase, course configuration (curved or linear), can be used to classify pressure-induced color changes in livor mortis into distinct postmortem time categories.

c. Calculation of surface areas formed by brightness courses may also enable classification of pressure-induced color changes in livor mortis into postmortem time categories. Clear differences were evident between measurements made before and after 20h p.m. Between 0 and 10h p.m. all L* value surface areas are positive, corresponding to easily-induced blanching. Up to 20h p.m. the medians reflect positive values. After 20h p.m., however, the medians become negative and declining L* courses predominate. Between 30 and 40h p.m. surface areas in the middle 50% of our data are only rarely positive; after 40h p.m. practically all surface areas are negative. Negative surface areas for L* courses, therefore, can be regarded as highly typical of late postmortem intervals. After 40h p.m. pressure applied to livor mortis almost never produces blanching. Courses with declining L* values correspond to the "fixed" livor mortis of Hilgermann (7) and can be explained by a "darkening" of the color due to hemoconcentration.

d. At high pressure (90N), a clear distinction can be made between the first 2 postmortem time categories (0–10 and 10–20h p.m.) based on changes in the chroma (C*) and brightness (L*) components of blanching in livor mortis. Changes in the chroma component during the first 20h p.m. follow a highly typical course and thus are especially suited for estimating time of death.

Considerable variations were noted in the courses of our color value measurements, chiefly due to the heterogeneous nature of the material. Many uncontrollable and unknown factors undoubtedly also influenced the results. Nevertheless, the study had to be designed to approximate to forensic practice, where reliable information on the history of the deceased and the circumstances surrounding death are not always available. The wide variations in our data can be attributed to factors such as basic skin color, antemortem physical condition, cause of death, ante and postmortem environmental factors, and storage conditions prior to measurement. Such variables must be taken into account when using the new measurement system to estimate time of death.

Ambient temperature is another factor that must be taken into account. We could confirm the finding of Fechner et al. that the blanching of livor mortis is strongly influenced by the surrounding temperature [5]. In our own investigations, blanching could be produced for a considerably longer period of time in cadavers stored at 4/5°C prior to the measurement procedure than in cadavers kept at warmer temperatures. This factor may also have been responsible for some of the striking variations in the color values we measured. In future the new measurement system can be refined, for example, to allow computer guided, subtle increases in pressure by means of a motor driven device. This would help to eliminate some of the irregularities arising from the use of a hand-driven screw.

The knowledge obtained in this study provides quantitative criteria that can be used for better estimation of time of death than is possible with the conventional method of applying thumb pressure to livor mortis and interpreting the subsequent blanching according to subjective impressions. The results presented here provide the basis for further studies to improve the new measurement system.

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