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Photometric measurement of color changes in livor mortis as a function of pressure and time

Development of a computer-aided system for measuring pressure-induced blanching of livor mortis to estimate time of death

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Summary. Until now, blanching of livor mortis in estimating time of death has generally been assessed based on subjective impressions, i.e. on whether blanching is visible after the application of pressure. We have developed a measuring system that uses digital processing to objectify the relationship between the pressure applied and blanching of postmortem lividity. The pressure is electronically registered by a strain gauge. At predefined levels (10, 20, 30, up to 100 N) the software triggers a color measurement by a commerically available tristimulus colorimeter. All parameters are measured in *a single* procedure and routed to the computer through a data interface. The pressureinduced color changes in the livor mortis are evaluated according to the L*, a*, b* system (CIE-LAB according to DIN 5033, DIN 6174), which closely approximates the physiology of sight. An additional color spacing formula (ΔE) allows analysis of color changes irrespective of the basic skin tone. Initial measurements on cadavers showed that application of increasing pressure produced regular courses of color changes in livor mortis.

Key words: Livor mortis – Blanching – Colorimetry – Measurement of pressure – Estimation of time of death

Zusammenfassung. Bislang wurde die „Wegdrückbarkeit" der Totenflecken bei der Todeszeitschätzung im wesentlichen nach subjektiven Eindrücken beurteilt – danach, ob die Totenflecke leicht, vollständig, schwer und/oder unvollständig wegdrückbar sind. Ein neues Meßsystem objektiviert die Beziehungen zwischen Kraftaufwand und Farbänderung der livores („Wegdrückbarkeit") durch digitale Verarbeitung von Meßgrößen. Der Kraftaufwand während des Drucks auf den Totenfleck wird mittels Dehnungsmeßstreifen elektronisch erfaßt. Bei Erreichen definierter Druckstärken (10, 20, 30 bis 100 Newton) löst ein Computerprogramm jeweils eine Farbmessung mit einem handelsüblichen Farbdifferenz-Meßgerät aus. Die Farbmetrik arbeitet nach dem Dreibereichsverfahren. Alle Parameter werden in *einem* Meßvorgang erfaßt und über einen Meßkonverter in einen Computer eingelesen. Die Darstellung des Farborts erfolgt im L,a b-System (CIELAB nach DIN 5033, DIN 6174), das der Physiologie des Sehens sehr nahekommt. Außerdem können Farbveränderungen über eine Farbabstandsformel (ΔE) weitgehend unabhängig vom Grundton der Haut analysiert werden. In ersten Ergebnissen von Messungen an Leichen zeigen sich regelhafte postmortale Abläufe der Farbveränderungen von Totenflekken bei zunehmender Druckstärke.

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

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Introduction

Livor mortis is one of a number of factors applied in forensic practice to estimate the time since death [5, 8, 12–14]. Lividity is a definitive sign of death caused by the accumulation of blood no longer circulating in the vessels of the skin [3, 18, 23]. In first appears 20–30 min postmortem and reaches its maximum extent in dependent areas of the body 6–9 h p.m. [20].

In the first hours after death livor mortis blanches under pressure. This blanching of livor mortis depends on the fluidity of the blood [5]. The fluidity steadily declines after death, primarily due to leakage of plasma into the surrounding tissue. Eventually, the livor mortis becomes truly fixed i.e. application of pressure does not produce blanching [6].

The temporal course of pressure-induced blanching of postmortem lividity has been investigated by many authors [4, 7, 15–17]. Mallach and Mittmeyer [16] carried out statistical analyses on the blanching of lividity under pressure applied by thumb or forceps and calculated mean values and their variability limits. A major problem in investigations of livor mortis is the standardization of test parameters, such as the level and duration of pressure and the degree of blanching.

v. Hunnius et al. [7] and Fechner et al. [4] standardized both pressure per surface area and its duration. v. Hunnius pointed out that the pressure required to produce blanching of livor mortis increases exponentially with time [7]. Fechner demonstrated a correlation between blanching and temperature: the lower the temperature the longer the period in which blanching could be produced [4]. Assessment of the blanching depended on the subjective optical impression.

The first systematic studies on the photometric characterization of cadaver skin were performed by Lins [10, 11]. Schuller et al. used colorimetry to determine the location of lividity on the color spectrum. They also measured color changes produced by applying hydraulic pressure to livor mortis and found an exponential dependence of the color changes on the postmortem interval [21, 22].

In order to provide an objective standard of measurement and ensure reproducibility we developed, in collaboration with the College of Gießen, a computer-aided color measuring system that quantifies both the pressure applied and the resultant color changes and then digitally processes the data obtained. The photometric measurement of pressure-induced changes in both the spectral components and color intensity of livor mortis was automatically calculated in a *single* procedure.

A holding unit was constructed to house both a colorimetric measuring head and a dynamometer to measure the pressure applied to the livor mortis. A data interface was developed to route the parallel measurements (colorimetric, pressure) to the computer for analysis.

Materials and methods

Hardware

To measure the *pressure*, a system was utilized that we had previously developed for evaluation of the thrust intensity of stabbing motions by means of a dynamometer housed in a hand grip [9]. For the *colorimetry* we chose the MICRO COLOR, manufactured by Dr. Lange GmbH, a color difference measuring instrument based on the tristimulus system. The MICRO COLOR consists of a data station, a portable measuring unit, and a flexible measuring head connected to the measuring unit by a fiber-optic cable. The tip of the measuring head contains an aperature 2 cm in diameter behind a quartz glass disc plate. To measure the pressure-induced blanching of livor mortis, the MICRO COLOR measuring head was installed in the hand grip so that its underside abutted directly against the dynamometer. This enables parallel measurement of the pressure applied and the resulting color changes in the livor mortis (Fig. 1).

Measurement of pressure

A dynamometer[1] with a maximum load capacity of 1 kN was used for pressure measurement. Strain gauges translate the pressure into an analogous, electrical signal. An amplifier must be used for optimal amplification of the weak signal (μV) given off by the dynamometer. Signals leaving the amplifier are routed directly to an analogue/digital converter, which translates the analogue voltage into a digital 8-bit signal. The 8-bit signal is fed to the computer through a ROM-Port (see flow diagram, Fig. 2).

An ATARI-ST series computer was chosen because it offered a high MHz-frequency, a userfriendly GEM operating system, and a large storage capacity at a relatively low price.

Color measurement

It was important that we procure a colorimetric system that delivered reproducible, reliable data based on generally recognized standards. The colorimetry is based on the German Industrial Standard (Deutsches Institut für Normung eV) DIN. Absolute determination of color is done in accordance with DIN 5033 colorimetry [1]. To measure color changes as compared to a reference standard, DIN 6174 colorimetric determination of color spaces is used [2].

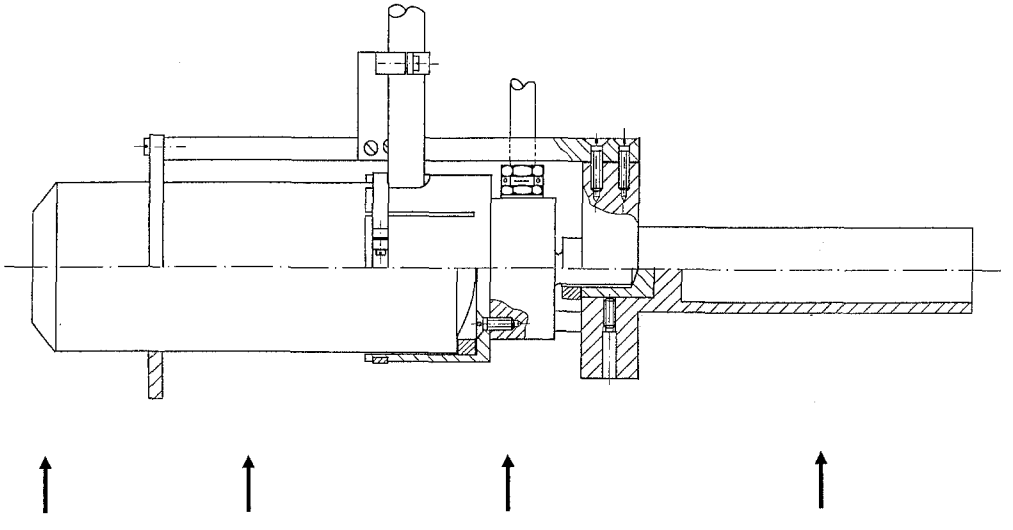

Fig. 1. Hand grip with measuring head and dynamometer

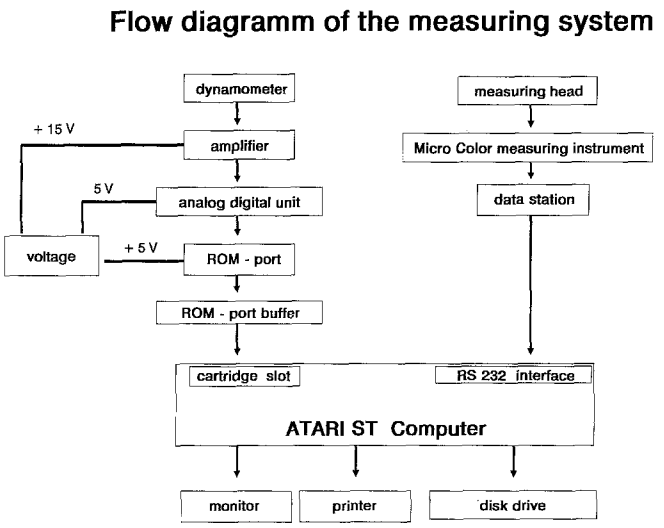

Fig. 2. Flow diagram

Theoretical basis of colorimetry. Colorimetry must take special account of the following [19]:

Physiological effects
- The "color value", i.e. the total effect on the observer,
- the processing of the color stimulus by the eye and the associated parts of the central nervous system.

Colorimetric definitions
- The systemizing (and standardization) of color measurement values, i.e. the correlation of color sensations to physical parameters,
- the graphic depiction of colorimetric values, including brightness.

Basic physical conditions
- The type of illumination, especially certain standard types of light (spectral radiance distribution).
- The object and its reflectance values.

The Standard Color Value system. Color parameters were standardized by the International Commission on Illumination (Commission Internationale de l'Eclairage = CIE). The resulting standard color values X, Y, and Z form the basis for the German Industrial Standard DIN 5033 colorimetry [1, 19].

Further development of the CIE system. The CIE system has the disadvantage that mathematically equal spacings in the color triangle are not perceived as equal. In the blue-violet range, for example, the smallest spaces are perceived as different, whereas in the green range mathematically larger intervals are not perceived. This drawback led to the development of systems for color space determination, such as CIE-LAB 1976 and DIN 6174 [2, 19].

Methods of color measurement

Two main colorimetric methods are generally used. The spectral method and the tristimulus method [19].

Colorimetry based on the spectral method proceeds in two steps: 1) the photometric measurement of light scattering (reflection) and 2) calculation of the associated color values. In the first step the probes is illuminated monochromatically (i.e. by a single wavelength) at intervals of a few nm in the range of visible light (380 nm–700 nm) and the reflected light measured as compared with an extremely white reference standard. This produces a reflection curve that shows the degree of reflection in terms of the wavelength. The second step consists of arithmetic analysis, in which the Standard Spectral Values of the corresponding standard light are now multiplied by the reflection values of the wavelengths. By forming the sum of the products the Standard Color Values X, Y and Z [1, 19] are obtained. This method is the more exact of the two, but also the more complicated and expensive.

In the *tristimulus method*, the 3 Standard Color-Matching Functions of observers with normal average color vision are reproduced and the resulting Standard Spectral Values measured by photoelectric receptors. This can be done by adjusting the sensitivity of the 3 measuring receptors to the Standard Color-Matching Functions, e.g. by use of color filters. Samples are illuminated by adjusting the filters according to the desired standard light, taking care to produce a homogeneous illumination. The tristimulus method directly registers the Standard Color Values X, Y and Z without, however, making any spectral photometric evaluation [1, 19].

We employ the tristimulus method in our system.

Measuring geometry and illumination geometry

The measurement of body surfaces depends principally on the *measuring geometry*, the *type of illumination*, and on the *illumination geometry*. The term measuring geometry denotes both the direction of the light source illuminating the body and the angle of the reflected radiation. A set-up using an Ulbricht globe as the uni-

[1] Manufactured by Hottinger Baldwin Messtechnik GmbH

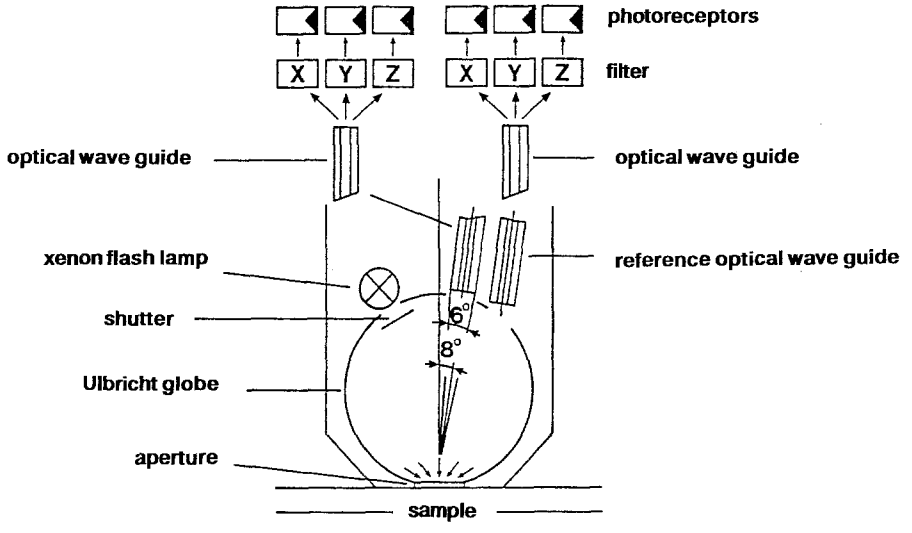

Fig. 3. Optical design of the color measuring head

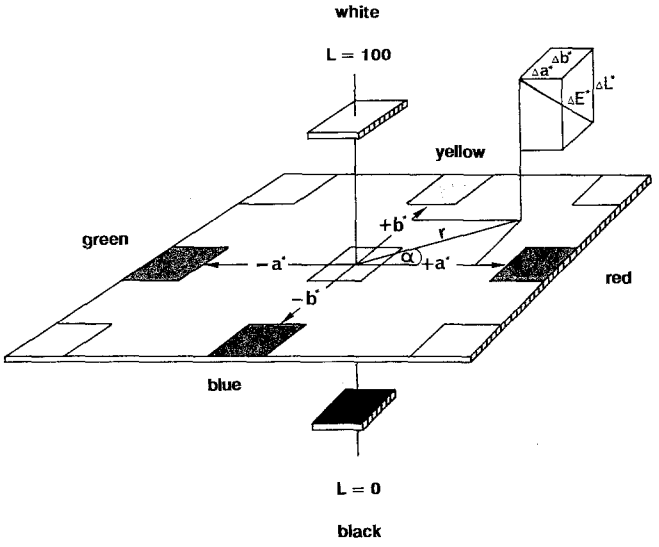

Fig. 4. CIE-LAB color system

versal measuring geometry is generally employed in accordance with DIN 5033 [1, 19]. The sample is diffusely (indirectly) illuminated through the Ulbricht globe and measured at an angle of 8° to the sample (Fig. 3). Two measurements are required in order to accommodate a possible change in the type of illuminating light caused by the sample (sample and reference). Samples are illuminated by a standardized light source. Because colors must always be measured under conditions approximating daylight, a standard light source D 65, which includes a UV-component corresponding to the spectral band of daylight, is advisable. The MICRO COLOR uses a xenon flash lamp whose light approximates the standard illuminant D 65 with appropriate filtering (Fig. 3). The light is split via an optical wave guide into the precisely defined 3 Standard Color Value measurement filters X, Y and Z. At the same time a second reference optical wave guide evaluates the light source and the globe surface. The light incident on the photoreceptors in each case is typical of the spectral reflection values R_x, R_y nd R_z.

Specification of color spacing in body colors (L, a*, b* system)*

The MICRO COLOR measuring instrument enables a colorimetric specification of *color spacings* according to the CIE-LAB formula. The L*,a*,b* system, based on sensory perception, developed by Judd and Hunter and standardized by the CIE in 1976 (DIN 6174, CIE-LAB 1976), is widely used in addition to the CIE color triangle [2, 19]. In the L*,a*,b* system, the L* 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 (+b = blue, −b = yellow) (Fig. 4). The L*, a*,b* coordinates are directly related to the standard color values X, Y and Z:

$$L^* = 116\,Y^* - 16$$
$$a^* = 500\,(X^* - Y^*)$$
$$b^* = 200\,(Y^* - Z^*)$$

Compared with the CIE color triangle, the L*,a*,b* system has the advantage that *mathematical* differences in *all* color ranges correspond to perceived color differences. In practice the L*,a*,b* system clearly recognizes color differences (ΔE) by the graphic depiction of perceived color spacings.

These spacings are calculated as follows:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

using the spatial pythagoras of the 3 different spacings [2]. Hence, ΔE* encompasses all color differences in a single arithmetic value. The L*,a*,b* system is especially suited for the quantitative specification of subtle differences in body color. The change in the color spacing ΔE produced by applying pressure to livor mortis allows a measurement of color differences scarcely influenced by basic skin tone (tint).

For some applications the DIN 6174 splits ΔE into a brightness component ΔL, a chroma component ΔC, and a hue (tone) component ΔH according to the equation [2]:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2}$$

The chroma component ΔC is established by the exponents P (sample) and B (reference)

$$\Delta C^* = C_P^* - C_B^* = \sqrt{(a_P^*)^2 + (b_P^*)^2} - \sqrt{(a_B^*)^2 + (b_B^*)^2}$$

The hue component is calculated in the same manner.

Software

The software was written to create a program that can:

1. log data over the parallel and serial interfaces,
2. compare and calculate data,
3. display data graphically on the monitor and in print-outs
4. store and retrieve data on diskettes.

The software was developed on a Turbo C Compiler by Borland. For the Atari ST the programmer language "C" has become the standard. The operating system GEM provides access to AES-, VID- and TOS-libraries.

The measuring system is operated by means of an user menu displayed on the monitor. Before a measurement is made, the number of measurements and level of pressure must be set. With increasing pressure continuous color measurements are triggered in increments of 10 N, up to a maximum pressure of 100 N. A time delay presents a too rapid increase in pressure, since the MICRO COLOR can carry out only one measurement approximately every 4 seconds (recharging of the xenon lamp). During application of pressure the computer gives an acoustic signal as each precalibrated pressure level is attained and simultaneously triggers a color measurement. The color changes are thus related directly to the pressure. After maximum pressure has been reached, color measurements may be continued at the same site *without* application of pressure. Color changes following the release of pressure, e.g. changes in the maximum achieved blanching, can be measured at 5-second intervals for up to 90 seconds.

Measurement procedure. In order to ensure standardization of the measurement sites, the body is placed in a supine position on a table with measurement openings. Livor mortis is measured only in the dorsal thorax and in the lumbar region. The continuous increase in pressure is accomplished by means of a screw mechanism that presses the measuring head upward against the liver mortis.

Results and discussion

We first tested the new measuring system on the upper arm of *living subjects*. A maximum pressure of 80 N was used, and an observation time of 45 seconds was set for color measurements after attainment of maximum pressure without further pressure. The MICRO COLOR measuring head was placed against an area of skin well supplied with blood (i.e. reddish) and pressure applied

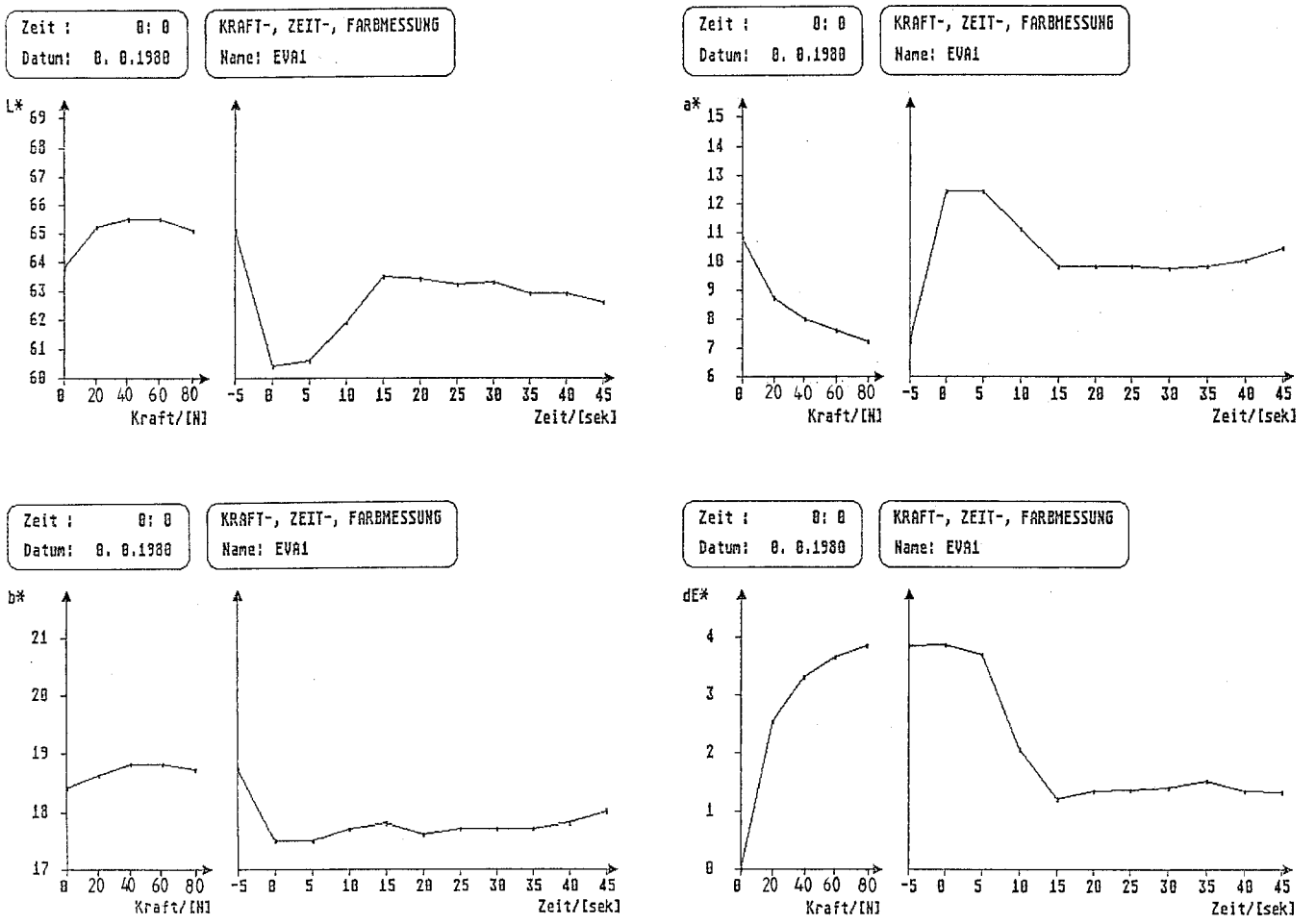

Fig. 5. L*, a*, b* courses in a living subject. L* = brightness, a* = location on red-green axis, b* = location on blue-yellow axis, dE* = total color change. The curves on the left show the color changes produced by increasing pressure; the curves on the right register color changes following release of pressure; the position "−5 sec" on the abscissa corresponds to the time immediately after release of (maximum) pressure

with gradually increasing force. Figure 5 shows an increase in the L* value on the light-dark axis, the brightness increasing colorimetrically. A perceptible increase or decrease in brightness can thus be depicted graphically in the L*,a*,b* color space. If pressure was released after reaching the maximum of 80 N, the brightness decreases abruptly (cf. the right curve). Initially, the skin area became darker than the value prior to application of pressure; further measurements showed a gradual return to the approximate starting value. The color position on the red-green axis in the same measurement first indicated a diminution of the a* value, i.e. a decrease in the red component. The skin area, which was reddish even before application of pressure, exhibited increased "blanching", with a diminished red component. Release of pressure occasioned a steep increase in the red component to values exceeding initial levels. Physiologically this corresponded to a short-term hyperemia due to the refilling of the capillary system.

Corresponding courses were also seen on the yellow-blue axis with a pressure-induced change in the b* value and finally in the color difference course ΔE* (the mathematic registration of all color changes in a single value). In addition to graphic depiction, the program can display or printout individual values, i.e. all L*,a*,b* coordinates and/or color differences (cf. Fig. 5).

Figure 6a–c show typical courses in the L*,a*,b* values of livor mortis subjected to increasing pressure at 3 different postmortem intervals. Representative curves depict color changes in the early postmortem interval (< 10 hours), after approx. 20 hours and after 2 days. A clear increase generally occurred up to 20 hours postmortem in the course of the L* (brightness) (Fig. 6a) and b* (blue-yellow axis) values (Fig. 6c), whereas the red-green axis exhibited a corresponding decrease in the a* value (Fig. 6b), representing diminished redness, i.e. a blanching; this tendency, however, decreased with time. An increase in brightness alone was almost never seen in the late postmortem interval. Instead, some cases showed a darkening at higher pressures, indicating a deepening in color as increased pressure was applied to "fixed" livor mortis on the second day postmortem. In some cases an increase in the b* value was evident even after 20 hours, occasionally being even more marked that the increase in brightness (L*). This could have been due to the particular basic skin color.

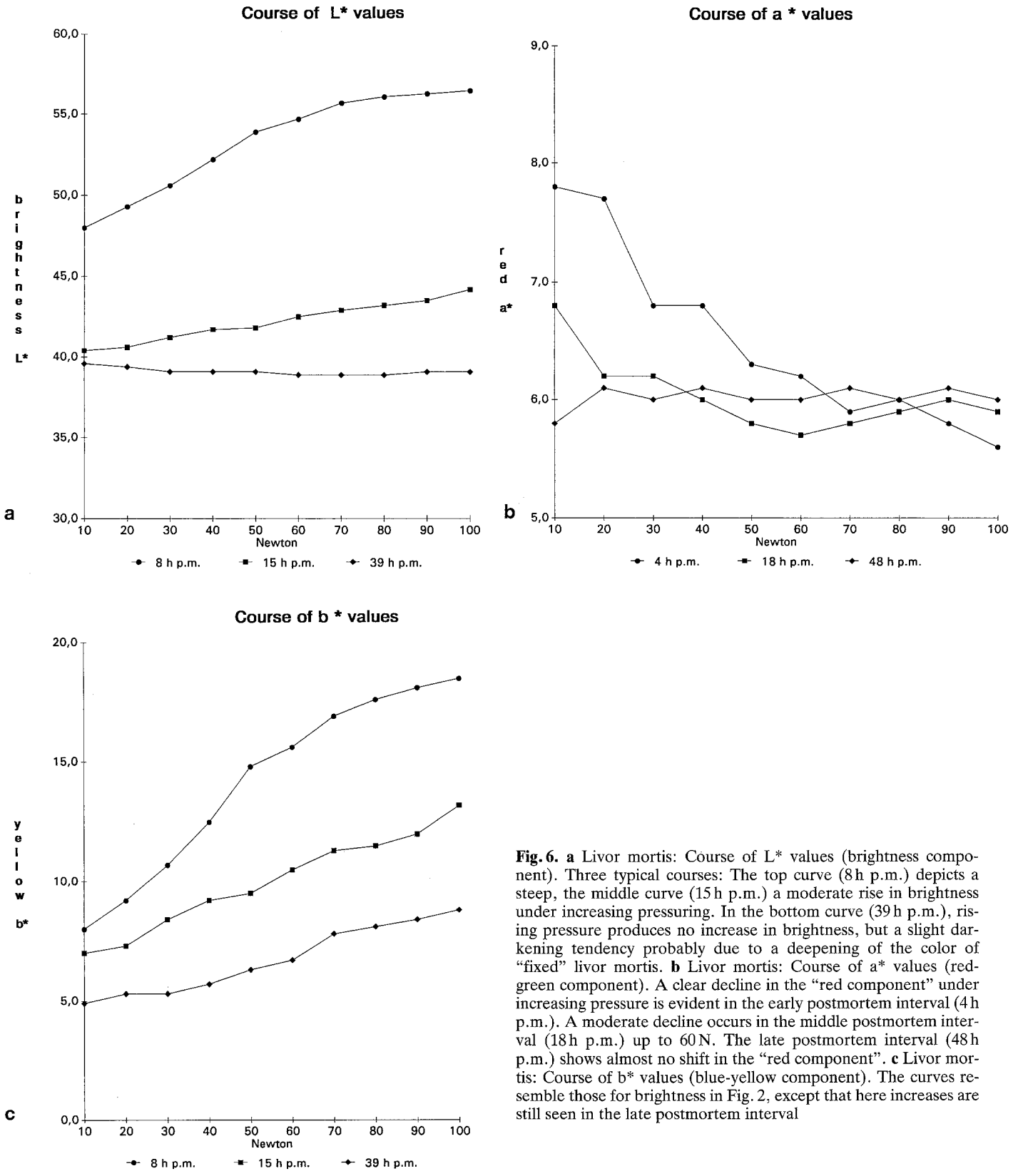

Fig. 6. **a** Livor mortis: Course of L* values (brightness component). Three typical courses: The top curve (8 h p.m.) depicts a steep, the middle curve (15 h p.m.) a moderate rise in brightness under increasing pressuring. In the bottom curve (39 h p.m.), rising pressure produces no increase in brightness, but a slight darkening tendency probably due to a deepening of the color of "fixed" livor mortis. **b** Livor mortis: Course of a* values (red-green component). A clear decline in the "red component" under increasing pressure is evident in the early postmortem interval (4 h p.m.). A moderate decline occurs in the middle postmortem interval (18 h p.m.) up to 60 N. The late postmortem interval (48 h p.m.) shows almost no shift in the "red component". **c** Livor mortis: Course of b* values (blue-yellow component). The curves resemble those for brightness in Fig. 2, except that here increases are still seen in the late postmortem interval

The method described here enables the gathering of objective data on pressure-induced blanching of livor mortis. Whether, and to what extent, *regular* postmortem courses in pressure-induced color changes in postmortem lividity can be established remains to be tested in serial measurements under standardized conditions on a large number of cadavers with known time of death. Until now, the blanching of livor mortis under pressure has generally been assessed according to subjective impressions. By providing objective standards for measur-

ing the pressure-induced blanching of livor mortis, the system presented here should encourage the wider use of this factor in determining time of death.

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