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TECHNICAL NOTE

PATHOLOGY/BIOLOGY

Michał Kaliszan,[1] *M.D., Ph.D., S.F.M.*

Does a Draft Really Influence Postmortem Body Cooling?*

ABSTRACT: Estimation of the time of death (TOD) is a very important task of forensic pathologist, and measurement of body temperature is a method deemed to be most precise during the initial postmortem period. The study aimed at verification of the significance of airflow present in the room where a corpse is found on body cooling process and hence on determination of the TOD. The experiment was performed in pigs during which the postmortem temperature of the eye, muscles, and rectum was recorded—in still air and with generated draft in the room. The results showed that the moderate airflow present in the experimental conditions did not significantly affect the course of cooling of the investigated body sites. Despite moderate wind generated in the room, the air movement close to pigs' bodies was actually minimal. This allowed to conclude that to evaluate the TOD most precisely, one should first have reliable data on the actual velocity of air in the direct vicinity of the body rather than relying on subjective sensation of the draft and using various unnecessary corrective coefficients for TOD calculation.

KEYWORDS: forensic science, time of death, postmortem body temperature, rate of the temperature decrease, eye temperature, draft, corrective coefficients

The postmortem body temperature decrease is an important factor in determining the time of death (TOD) in humans, and temperature-based methods of TOD estimation are deemed to be most precise during the first several hours after death (1). Measurements of the rectal temperature are commonly used, at least in Europe, in estimating the TOD (2–6). Valuable results have also been obtained from temperature measurements of the brain (7), heart muscle (8), liver (9), and tympanic membrane (10). However, despite multiple attempts to develop a precise method of TOD estimation based on body temperature measurement, their accuracy still leaves a margin for improvement. During the first 6-h postmortem, there is at least a 3-h margin of error, which increases to at least 4–5 h around 20–24 h after death. Another obstacle in precise TOD estimation using rectal body temperature measurement is the presence of the plateau phase (a phase of significantly retarded cooling) during the first 3-h postmortem (1). Recently, promising results using the eye temperature in estimating the TOD in the first several hours postmortem with an error approximately ±1 h were obtained, mainly thanks to the lack of the plateau phase in this body site (11,12).

It is assumed that the most precise TOD evaluation method is one which takes into account multiple additional factors, that is, ambient temperature, body mass, thickness of clothing, and environmental conditions including air movement at the scene, which are considered in the Henssge formulae: for ambient temperature up to 23°C

$$T_r - T_a/37.2 - T_a = 1.25\exp(Bt) - 0.25\exp(5Bt) \qquad (1)$$

or for ambient temperature above 23°C

$$T_r - T_a/37.2 - T_a = 1.11\exp(Bt) - 0.11\exp(10Bt) \qquad (2)$$

where T_r, measured rectal temperature; T_a, ambient temperature; $B = -1.2815(m^{-0.625}) + 0.0284$; m, body mass [kg]; t, TOD (5). As these equations are very complicated and cannot be solved without scientific calculator or computer program, Hennsge constructed a special nomogram, allowing to easily "draw" the TOD. Depending on the clothing, air movement, and humidity, the real body mass considered in the formula or nomogram should be multiplied by a corrective coefficient ranging from 0.35 to 2.8 (5,6). Therefore, taking into consideration possible known additional factors allows, in theory, to improve TOD estimation. Nonetheless, there is a question, considering such a significant margin of error (at least ±3 h), whether the application of corrective factors recommended by some researchers (5,6) actually improves its precision or not. For example, a case of a dead 70-kg body wearing two layers of clothing (what requires multiplying body mass by 1.2 in Henssge formula) found at home at temperature 20°C, with a rectal temperature of 34°C. If in such a case one uses either a simple method, not requiring corrective coefficients, like a "rule of thumb" (more common in the United States) based only on body temperature and the assumption that the body cools after death at a rate of 1°C/1 h and there is a necessity to add 3 h regarding the mentioned plateau phase or Henssge nomogram (used in Europe) taking into consideration multiple corrective coefficients for TOD estimation, the predicted TOD for both methods is 6 ± 3 h. If the above-mentioned body was naked and no correction of Henssge formula is needed, the calculated TOD is 5 ± 3 h (1). Therefore, despite using corrective coefficients for body mass and clothing in the Henssge method, the margin of error for both methods is large and similar.

In a recent article (11), the question was studied to what degree the cooling rate depended on the body mass (in the range between 81 and 124 kg) and whether the adoption of the recommended

[1]Department of Forensic Medicine, Medical University of Gdańsk, ul. Dębowa 23, Gdańsk 80-204, Poland.

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corrective coefficient for body mass (5,6) significantly increases the precision of the TOD estimation. The correlation analysis failed to confirm the practical value of this corrective factor for the improvement of TOD estimation in the studied range of body masses (81–124 kg, which correspond to normal and obese body mass of an adult). It was shown that correlations between the body masses of pigs and the cooling rate were very weak for muscles and rectums, and no correlation was found at all for eyeballs and orbit soft tissues. Even when individual cases were taken into consideration, the chances of improving the TOD estimation using an exponential equation corrected for the body mass of a given individual were still low (11). This gave grounds for questioning the necessity of applying corrective factors for body mass between normally built and nourished adults for the purpose of TOD estimation.

After analyzing the results of the study focused on the evaluation of the temperature plateau in the initial period of postmortem cooling of the eyeballs and orbit soft tissues (12), the practical lack of significance of moderate airflow for the cooling process in these specific sites was also suggested.

Findings referring to eyeball and orbit tissues were related to those concerning body sites to date considered in forensic pathology, that is, the rectum and muscles.

Materials and Methods

The study was carried out in two series of Great Polish White pigs. The first part of the study was conducted in 19 pigs weighing between 81 and 124 kg, while the second part was conducted in 10 pigs weighing between 80 and 114 kg. Measurements were performed using five two-channel thermometers P655 connected with pin probes Pt100, class B 1/3 DIN, 100×1.4 mm, ending in a 20-mm temperature sensor or with pin probes Pt100, class B, 150×3 mm, ending in a 40-mm temperature sensor (Dostmann–electronic GmbH, Wertheim-Reicholzheim, Germany).

The investigated pigs were killed by electrical current applied to their backs. The killing procedure and study were performed according to guidelines of the local ethical committee for studies on animals. Directly upon termination, two animals at a time were placed with the abdominal surfaces facing 150-mm-high wooden gratings, in a specially assigned, isolated room 48 m^3 in volume. After putting on an eyelid spreader to obtain a wide lid slit, eyeballs were stabilized with pincers. Pin probes (Pt100, class B 1/3 DIN) nos. 1 and 3 were inserted into the sclera around the nasal quadrants of the left eyeballs, 3 mm away from the corneal limbus, passing through the pars plana of the ciliary body into the vitreous chamber until a depth of 22 mm was reached. Pin probes nos. 2 and 4 were inserted into the soft tissues of the right orbits at the medial canthus, passing along the medial rectus muscle toward the superior orbital fissure, until a depth of 25 mm was reached. During the measurements, the eyelids were naturally closed. Pin probes nos. 5, 6, 7, and 8 (Pt100, class B) were inserted up to their handles (150 mm) into the rump muscles and the rectum. Probes nos. 5 and 6 were inserted in the muscles of the left rump from the point of insertion localized in the central portion of the rump. Probes nos. 7 and 8 were placed in the rectum. Ambient temperature was measured with probe no. 9 placed 500 mm above the floor. The nine probes used for each measurement were located in parallel with the floor, and their handles were stabilized in the grips of the stands. The thermometers were connected to a computer, and temperature values were recorded with an interval of 5 min. Recording of measurements started after 75 min, as this time was needed for preparing the animal and connecting the equipment. The temperature recording was completed approximately 15 h after the animals' death.

To ensure airflow and ambient temperature reflecting room conditions, two air conditioners K-2700 (nozzle outlets 0.1×0.35 m), manufactured by Elhurt Klima (Warsaw, Poland), and an XS40C2 fan, manufactured by Sanico (Warsaw, Poland), were used. The air conditioners were positioned with their nozzles facing each other, outward in relation to the animals, at the level of their heads. The air conditioners and the fan were located 2.8 m apart in the corners of the equilateral triangle which they formed. The nozzle outlets of the air conditioners and the propeller of the fan were 0.8 m above floor level. The fan was placed behind the rump line. The distance between either of the air conditioners and the neighboring head of animal was 0.8 m. The distance between the fan and the heads of the animals was 2.5 m each (Fig. 1).

The air velocity was measured using a Testo 452 thermal anemometer connected with an NTC isotropic probe in the shape of a sphere with a diameter of 4 mm (Testoterm GmbH, Lenzkirch, Germany). The air velocities were measured in the following locations: 2, 5, 10, 15, 20, 30, 50, and 100 mm away from the orbits and rumps, 100 mm away from the nozzles of the air conditioners and the fan propeller and 100–150 cm above floor level within the triangle formed by the air conditioners and the fan.

A mathematical model was developed to quantify the cooling of various pig body sites after death. For this purpose, Newton's law of cooling was applied:

$$T = T_a + (T_0 - T_a)\exp(-k_c t) \quad (3)$$

where T is the temperature of the studied body site, T_a is the ambient temperature, assumed to be constant during the course of the study, T_0 is the initial temperature, k_c is a first-order cooling rate constant, and t is the time since death. The data were processed with Matlab® Software version 7.0 (The Math Works, Inc., Natick, MA). The estimation was performed via the least squares method implemented in Matlab's *nnlinfit* function. The precision of the parameters estimated was assessed by calculating the coefficient of variation (% CV) using the *nlparci* function. The closer CV is to zero, the more precisely the parameter was estimated.

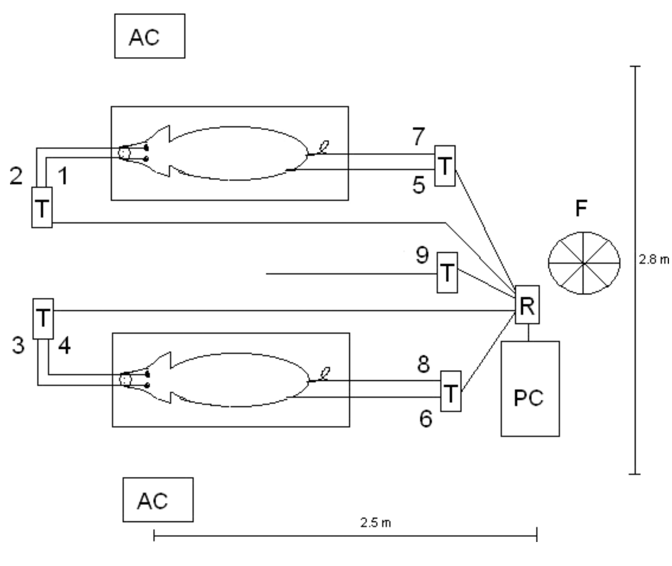

FIG. 1—*Scheme presenting location of pigs and ventilation equipment during the experiment: T, thermometer; AC, air conditioner; F, fan; R, recorder; PC, computer. Probes are numbered from 1 to 9. Distances are given in meters.*

The influence of airflow on the cooling rate was tested comparing the individual estimates of the cooling rate in the first and the second part of the study. A *t*-test was performed to test the hypothesis that individual estimates of cooling rate with and without air flow are independent random samples from the same normal distribution with equal mean and variance. If the tested hypothesis is true, one can assume that there is no effect of airflow on the particular parameter. Additionally, the relative difference (RD) was calculated as a difference between the mean individual estimates of study 1 and study 2 divided by the value of study 1 to assess how big the difference between the parameters is. The calculations were carried out using Microsoft Excel 2000 (Microsoft Corporation, Redmond, WA).

Results

Figure 2 illustrates the time courses of temperature decrease in the eyeballs, orbit soft tissues, muscles, and rectums, along with the time courses of ambient temperature for both experiments. The parameter estimates obtained by the nonlinear curve fittings are listed in Table 1. All parameters were estimated with high precision, as confirmed by small coefficients of variation (%CV).

During both parts of the experiment, the ambient temperature was almost constant. The mean ambient temperature was 21.0 and 20.2°C in studies 1 and 2, respectively.

The mean initial temperature of the eyeball was estimated as 36.1 and 34.8°C for studies 1 and 2, respectively. For the orbit soft tissue, it was comparable and equaled 36.5 and 35.6°C for studies 1 and 2, respectively. On the contrary, the initial temperature of muscles and rectums was higher and equaled 41.6 and 42.4°C for the rectum and 41.3 and 42.1°C for muscles in studies 1 and 2, respectively. As the model does not take into account the initial phases of cooling, the estimated T_0 should be treated as apparent. The presence of the plateau for the rectum and muscle led to a higher T_0, whereas the presence of a more rapid phase led to a lower T_0 than the true one.

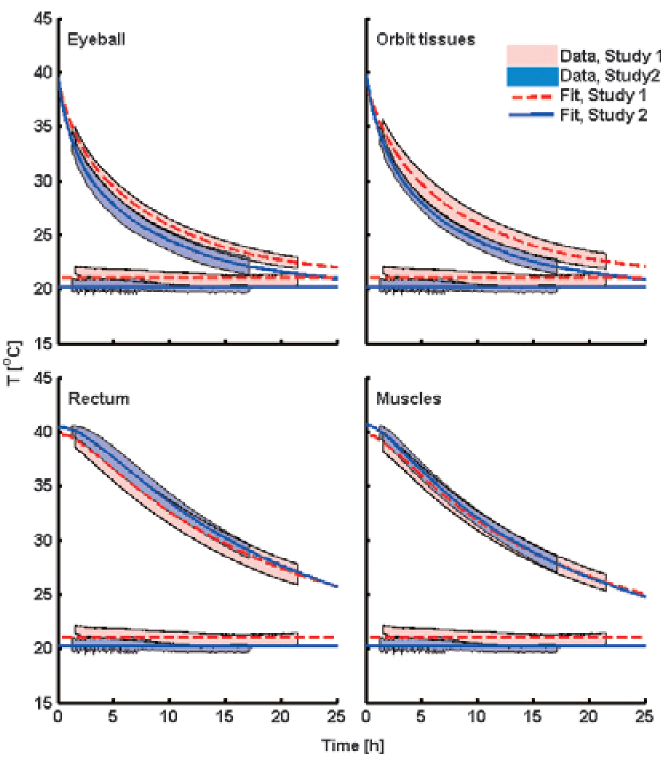

FIG. 2—*The time course of measured temperature of the pig eyeballs, orbit soft tissues, muscles, rectums, and environmental temperature (T). Red and blue represent the first and second part of the study. The filled area is a mean ± standard deviation of the measured temperatures. The dashed and continuous line represent the best fit obtained by using Eq. 3 for the first and the second parts of the study.*

The mean values of the cooling rate of eyeballs were estimated as 0.113 (±0.013) h^{-1} and 0.125 (±0.029) h^{-1} for studies 1 and 2, respectively. The cooling rate of orbit tissues was comparable and equaled 0.112 (±0.013) h^{-1} and 0.131 (±0.025) h^{-1} for studies 1 and 2, respectively. The cooling rate of muscles and rectums was much smaller and equaled 0.058 (±0.006) h^{-1} and 0.052 (±0.004) h^{-1} for the rectum and 0.064 (±0.005) h^{-1} and 0.062 (±0.007) h^{-1} for the muscles in studies 1 and 2, respectively.

The first part of the study was conducted in still air. The velocity of air in the second part of the experiment near the outlet of each air conditioner and near the fan propeller reached 4–5 m/sec and 3–4 m/sec, respectively, and corresponded to 3° of wind force (light breeze) on the Beaufort scale (13). The velocity of air decreased as a result of dissipation of the air streams so that at 100–150 cm above floor level, within the triangle defined by the location of the air conditioners and the fan, it decreased and reached its center value of 1.7–2.3 m/sec, which corresponded to 2° of wind force (light air) on Beaufort's scale, reaching locally 1.0–1.2 m/sec, which corresponded to 1° of wind force (faint air) Beaufort scale (13). At a distance of 50–100 mm away from the orbital regions and rumps, the velocity of air was constant and equaled 0.3–0.4 m/sec. Approaching the eyelids, the velocity decreased and reached 0.06–0.10 m/sec at 2 mm away from the eyelid slits. The velocity of air near the pigs' bodies is shown in Table 2.

To assess the impact of airflow on the cooling rate of the studied body sites, the model parameters were obtained individually for each animal and compared as presented in Table 3. The RD between the estimated parameters for studies 1 and 2 is <15%. The highest was determined for eyeballs and orbit tissues as −10.2% and −15.0%, respectively. To statistically verify these results, a

TABLE 1—*The parameter estimates of the proposed mathematical model (Eq. 3) obtained from the fittings to the mean temperature of the studied pig body sites.*

Site of Measurement	Parameter	Study 1	Study 2
Eyeball	T_o [°C] (%CV)	36.1 (0.04)	34.8 (0.18)
	k_c [h^{-1}] (%CV)	0.113 (0.15)	0.125 (0.62)
Orbit tissues	T_o [°C] (%CV)	36.5 (0.04)	35.6 (0.18)
	k_c [h^{-1}] (%CV)	0.112 (0.14)	0.131 (0.60)
Rectum	T_o [°C] (%CV)	41.6 (0.03)	42.4 (0.10)
	k_c [h^{-1}] (%CV)	0.058 (0.10)	0.052 (0.46)
Muscles	T_o [°C] (%CV)	41.3 (0.03)	42.1 (0.11)
	k_c [h^{-1}] (%CV)	0.064 (0.10)	0.062 (0.44)
Environment	T_a [°C] (%CV)	21.0 (0.02)	20.2 (0.07)

TABLE 2—*The airflow velocity close to the pigs' orbits measured with an anemometer.*

Distance from Orbits (mm)	Airflow Velocity (m/sec)
2	0.06–0.10
5	0.08–0.10
10	0.11–0.15
15	0.13–0.17
20	0.22–0.26
30	0.23–0.33
50	0.27–0.35
100	0.31–0.38

TABLE 3—*Assessing the influence of air flow on the cooling of various pig body sites. The m and SD represent the mean and standard deviation of the parameter estimates obtained for individual pigs. The* t-test *was performed by testing hypothesis H that there is no difference between given parameter for studies 1 and 2. Value of 1 denotes that the hypothesis can be rejected (parameters are different); 0 denotes that the hypothesis can be accepted (parameters are not different) with 5% of statistical significance. The* p-value *shows the probability of observing the given result by chance, if the null hypothesis is true. %RD denotes relative difference calculated as the difference between mean parameter estimates for studies 1 and 2, divided by the mean value of parameter estimate for study 1. The calculations were conducted for the whole data set and for the part of the data regarding the later phase (after 2-h postmortem).*

		Study 1		Study 2		*t*-Test		
Site of Measurement	Parameters, [units]	m	SD	m	SD	H	*p*-Value	%RD
All data								
Eyeball	k_c [h^{-1}]	0.113	0.013	0.125	0.029	0	0.130	−10.2
Orbit tissues	k_c [h^{-1}]	0.112	0.013	0.131	0.025	1	0.036	−15.0
Rectum	k_c [h^{-1}]	0.058	0.006	0.052	0.004	0	0.062	8.1
Muscles	k_c [h^{-1}]	0.064	0.005	0.062	0.007	0	0.424	2.7
Later than 2 h since death								
Eyeball	k_c [h^{-1}]	0.111	0.013	0.120	0.027	0	0.217	−8.3
Orbit tissues	k_c [h^{-1}]	0.110	0.012	0.124	0.025	0	0.063	−13.0
Rectum	k_c [h^{-1}]	0.058	0.006	0.055	0.005	0	0.108	6.7
Muscles	k_c [h^{-1}]	0.064	0.005	0.062	0.007	0	0.459	2.8

paired *t*-test was performed. The results suggest that the cooling rate was not statistically different between the studies for muscles, rectum, and eyeballs. The difference was only confirmed for the orbit tissues. To some degree, the results of comparison can be affected by the use of a simplified model. As the terminal phase allows to determine k_c precisely, the *t*-test was repeated using the data from 2 h after death and showed no statistical difference for all the studied body sites (Table 3).

Discussion

The temperature recording started 75 min after the animals' deaths, thus limiting the ability to describe the initial part of the cooling. It can be deduced from the visual inspection of Fig. 2 that the model slightly misses the initial part of the data. Specifically, the cooling of the eyeballs and orbit soft tissues revealed a biphasic pattern with the more rapid phase observed in the initial 2- to 3-h postmortem. For the muscles and rectum, the cooling appears to be constant (plateau of body cooling) in the initial 3- to 4-h postmortem. Despite the difference in the initial phase, the remaining time course exponentially decreases toward the ambient temperature. The simple single-exponential mathematical model was used for the sake of simplicity and because of the inability to resolve parameters in the more complex models, that is, those accounting for a bi-exponential decline.

The comparison of the terminal k_c resulted in the conclusion that the cooling rates of all the studied tissues were not statistically different between the studies. These show that the influence of air flow is rather minimal on the cooling rate (later than 2 h after death) for all the considered body sites, although there can be some influence in the initial phase, which is difficult to quantify based on the current study design as such differences do not necessarily result in differences in airflow immediately adjacent to the body.

The kinetics of the cooling of the investigated sites under the conditions of the present experiment are well described by the single-exponential model of cooling. This model appears to be reliable and can be used to estimate the time elapsed since death based on the temperature measurements of the proposed body sites. The single-exponential models of cooling from both studies, starting 75-min postmortem, were compared. In the first part of the experiment, the air was still, while in the second part, the air movement was generated artificially. In the second part, the mean airflow at 100–150 cm in the zone projecting onto the animals was 1.7–2.3 m/sec. This velocity applies to the wind generally felt as weak and corresponds to moderate drafts (13). However, the velocity of wind in the experimental region considerably departed from these values. In the direct proximity to the eyelid slit, it equaled only 0.06–0.10 m/sec and progressively increased reaching 0.3–0.4 m/sec at a distance of 50 mm and 100 mm away from the eyelids (Table 2). This range of airflow velocities applies to a wind commonly described as weak and corresponds to mild drafts (13). This satisfied the author's expectations, as the initial intention of the study was to find an optimal formula for the estimation of the TOD in room temperature under closed room conditions, which is an especially frequent setting of criminal deaths (11,12). Based on literature data (14), such a velocity of air (0.3–0.4 m/sec) cannot affect the rate of postmortem body temperature decrease, including the eyeballs and the orbit tissues. It was also demonstrated by the same authors (14) that in the case of an immobile and unclothed human body, the air at a velocity of ≤0.5 m/sec does not have a significant effect on heat loss because the heat convection in such conditions is not higher than in still air. This value with respect to the areas adjacent to the eyeballs, the orbit tissues, and also rumps was not exceeded in the present experiment, and the airflow conditions in these areas corresponded to a situation comparable to still air (13,14). The analysis of the data indicates that using correction coefficients for the TOD estimation accounting for the velocity of airflow felt in the room during the experiment (moderate wind/draft) has no significance. This especially applies to clothed corpses in areas in which the threshold velocity of airflow above which the effect on body cooling starts to be significant is 0.8 m/sec. Air at this speed does not pass underneath the outer garments (trousers, shirt, and underclothes) and does not affect the paramural layer; hence, the rate of cooling of a clothed body is not dependent on such a low air velocity, although it should depend on its temperature (14). This therefore explains the rather surprising consistency of the rate constants of the temperature decreases in the investigated sites, despite the different experimental conditions.

The mean initial temperature was found to be statistically different between the two studies. This might be a consequence of the different initial temperature of the animals' body sites. It could also be as a result of the limited number of animals used in the study. However, it did not affect the results of the studies.

Conclusions

A comparison of the results of both parts of the study of pigs' postmortem body temperature measurements seems to show that moderate airflow present in the experimental conditions designed in the study does not affect the cooling of the eyeballs, orbit tissues, muscles, and rectum, hence probably also other body sites. If these findings are complemented by the observation of the practical absence of the effect of body mass on the TOD estimation model (11), then the question arises concerning the sense of using the recommended correction coefficients as presumably accounting for the effects of a number of endogenous and exogenous factors on precise TOD estimation (5,6). Therefore, to estimate the TOD as precisely as practically possible, one should first have reliable data on the actual velocity of air in the direct vicinity of the body, rather than to rely on the subjective sensation of the draft. One can imagine a situation in which a dead body lies on the floor, for example, in the corner of the room, the window is open, alternatively an air conditioner or a fan is switched on, and the wind can be felt by the persons performing the investigation. However, in practice, it may often appear that close to the body, the airflow is minimal. In such a situation, the ambient temperature is definitely influential on TOD estimation, but not airflow.

The comprehensive studies verifying the presumed value of the eye temperature measurements for TOD estimation and the influence of airflow in experimental conditions will be continued on a larger number of human bodies.

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Additional information and reprint requests:
Michał Kaliszan, M.D., Ph.D., S.F.M.
Department of Forensic Medicine
Medical University of Gdańsk
ul. Dębowa 23
Gdańsk 80-204
Poland
E-mail: michalkal@gumed.edu.pl