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# Eye temperature measured after death in human bodies as an alternative method of time of death estimation in the early post mortem period. A successive study on new series of cases with exactly known time of death

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ABSTRACT

The paper presents a continuation of the studies on time of death (TOD) estimation based on post-mortem temperature measurements in the human eyeball. In the current study, single (in 20 patients) or double (within a 1-hour interval in 10 patients) eyeball and rectal temperature measurements were taken in patients who died in the University Hospital Intensive Therapy Unit. The actual TOD in each patient was exactly known and the body temperature was recorded shortly after (between 50 min and 3 h 30 min). The temperature was measured using pin probes connected to a high precision electronic thermometer. The measured eye temperatures ranged from 27.4 to 33.7°C. The ambient temperature in all cases was stable (22 °C), which corresponded to the usual room temperature. Post mortem interval (PMI) was calculated using a formula based on Newton's law of cooling, previously successfully applied in comprehensive studies on pigs and recent studies on human bodies. Thanks to knowledge of the exact TOD and the stable ambient temperature, the current study on 30 new cases allowed the method to be improved by adjusting the mean value of the cooling constant and the initial eye temperature in comparison to recent studies.

## 1. Introduction

The determination of the time of death (TOD) is a very important task in forensic medicine. The precision of the determination of the time at which the act resulting in the victim's death was committed is often a decisive factor behind the success of the investigation conducted by the police with a view to the establishment of the perpetrator of the act, often involving his/her identification from among suspects, and followed by a court sentence. In the case of the detainment of the suspect, knowledge concerning the victim's TOD allows the interrogation of the suspect in terms of his/her presence at the scene at the time of the victim‘s death, and the verification of the alibi, if any. Unfortunately, the practically available methods for the determination of the TOD are based on the observation of post-mortem changes, and, due to a considerable number of factors affecting the course of such changes, are burdened with a significant level of error [1–3]. Currently, Henssge's method based on the measurement of body core temperature is considered to be of the highest proven effectiveness, especially during a period of up to several dozen hours after death [4]. However, the method is most reliable when applied between about 6 h and 36 h after death, i.e. until the time when, due to cooling, the body temperature reaches the ambient temperature. In turn, during the first few hours after death, the precision of the TOD estimation is seriously impaired by the so-called plateau effect, dependent on the storing of heat in the body tissues and their residual metabolism, which continues for a few hours after death [5]. As for recent research into the improvement of the precision of methods based on core temperature measurement, it was the experimental development of a database of post-mortem rectal cooling which turned out to be useful in practice [6]. Although other works are promising, they nevertheless present very complex mathematical calculations and are at the stage of further research [7–10].

The research conducted for the last few years on dead human bodies revealed the potential possibility of decreasing the error in the estimation of the TOD within a few hours after death owing to the measurement of the temperature in the eyeball, in addition to the measurement of the rectal temperature. This results from the small or virtually non-existent impact of the plateau effect on the temperature in the eyeball [5,11–14].

Currently, another series of examinations of the bodies of patients who died in the Intensive Therapy Unit of the University Hospital has

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been conducted; in this case, the TOD could be established precisely owing to the fact that the patients were connected to devices monitoring their vital parameters. Such precise data concerning the actual TOD were not available in the previous studies, where information on the TOD was based on the testimonies given by witnesses present at the death or camera (CCTV) recordings showing the moment of a fall/fainting, but not necessarily the death.

The aim of the present study was to improve the method of TOD estimation in the first few hours after death during the plateau-time of the rectal body temperature based on post-mortem eyeball temperature measurements.

## 2. Materials and methods

The eyeball and rectal temperatures were measured at the University Hospital Intensive Therapy Unit during successive body examinations of 30 human individuals, who died between the years 2012 and 2016. In the case of 20 dead bodies, the measurement was carried out once within 50 min to 3 h 20 min after death, and in the subsequent 10 cases, the measurement was performed twice, with a one-hour interval, within 1 h to 3 h 30 min after death. This manner of conducting examinations made it possible to obtain a total of 40 results of individual measurements. The measurements were performed on the bodies of humans hospitalized in the University Hospital Intensive Therapy Unit, having died of different causes, but with body temperatures ranging from 36.5 °C to 38 °C at the moment of death – the body temperature before death and at the moment of death was measured with use of infrared clinical thermometer. Directly after confirming death, the bodies were transferred from the hospital bed onto a metal trolley which surface was previously covered with thick plastic body bag to isolate the body from the metal surface. After putting the body on the trolley it was moved to the isolated “post-mortem” room located on the same floor of the building where it was lying naked during the experiment. After death, in all dead bodies the eyelids were closed. Thanks to air conditioning in the room where the bodies were examined, the ambient temperature was constantly stable at 22 °C.

Post mortem temperature measurements were performed using a high precision two-channel electronic thermometer – a “TOD-meter” (P 755PT) (Fig. 1) connected with removable probes: a thin one with a sharp end 100x1.4 mm, with a 20 mm temperature sensor (for the eyeball), and a thicker one 150x3 mm, ending in a 40 mm temperature sensor (for the rectum). The thermometer was equipped also with an ambient temperature sensor. The thermometer and probes were manufactured by Dostmann–electronic GmbH, Wertheim-Reicholzheim, Germany. The method of temperature measurements was the same as in the previous study [11].

The thin pin probe was inserted through the eyeball sclera into the vitreous chamber until the 20-mm-long sensor was fully immersed. Another thicker pin probe was inserted up to its handle (150 mm) into the rectum. The ambient temperature was also measured in close vicinity to the body with the use of the temperature sensor attached to the thermometer.

Mathematical processing of the study results was carried out using Microsoft Office Excel 2016 (Microsoft Corporation, Redmond, WA).

The study was performed according to the regulations of the Ethics Committee for Studies on Humans of the Medical University of Gdansk (Approval no. NKEBN/144/2010). The use of a very thin probe caused just a tiny injection mark in the sclera, therefore the manner of the temperature measurement caused no visible defect to the eyeball.

## 3. Results and discussion

A mathematical model, previously developed using Newton’s law of cooling to quantify the cooling of various pig body sites after death [12] and already tested in recent studies [13,14], was applied for the post mortem interval (PMI) calculation of the 30 human bodies in the current study:


**Fig. 1.** The “TOD-meter” (P 755PT) with probes: 1) a sharply ended thin pin probe for eyeball temperature 2) thick pin probe for rectal temperature and 3) sensor for ambient temperature.

$$T = T_a + (T_0 - T_a)\exp(-k_c t) \quad (1)$$

where $T$ is the temperature of the studied body site (in calculations it was the mean of $T_1$ and $T_2$ listed in Table 1), $T_a$ is the ambient temperature, assumed to be constant during the course of cooling until the moment of the measurement, $T_0$ is the initial human eye temperature, $k_c$ is the first order cooling rate constant and $t$ is the time in h which passed since death (PMI).

In the previous study, conducted on 30 bodies of persons who died a sudden death outside hospital, it was determined that when $k_c = -0.113\,h^{-1}$ in the (Eq. (1)) formula, the prediction of the determination of the PMI is satisfying. In that previous study, the optimal similarity was obtained for $T_0 = 34.5$ °C and $k_c = -0.113\,h^{-1}$, where RMSE (root mean square error) = 0.51 h and the 95% confidence interval was ± 1 h [11].

In the current study involving examinations of dead bodies, in which it should be assumed that the TOD was known with considerably higher precision than previously, the use of $k_c = -0.113\,h^{-1}$ and $T_0 = 34.5$ °C in the formula brought about a re-evaluation of the PMI: the PMI determined in this way was slightly longer than in reality in the majority of cases. In view of the above, in order to acquire the best precision of the PMI determination, new data were subjected to a mathematical analysis, as a result of which an optimum prediction of the determination of the time of death was obtained for the following parameters: $k_c = -0.2\,h^{-1}$ and $T_0 = 35$ °C. The above also made it possible to round off the value of $k_c$ to the first decimal place, and showed the absence of a significant improvement in the precision when the value of the coefficient $k_c$ was given to the third decimal place. In the present study, the optimal similarity was obtained for $T_0 = 35$ °C

**Table 1**
Results acquired during the study for 30 bodies (40 temperature measurements). $T_1$, $T_2$ – eyeballs temperature, $T_r$ – rectal temperature, PMI – post mortem interval in hours/minutes, Δ PMI – difference between actual and predicted PMI in hours/minutes, RMSE – root mean square error, N – number of cases. Ambient temperature was constant (22 °C) in all cases.

| Case no. | $T_1$, °C (eyeball 1) | $T_2$, °C (eyeball 2) | $T_r$, °C (rectal) | PMI (actual) | PMI (predicted) | Δ PMI |
|---|---|---|---|---|---|---|
| 1 | 33.4 | 33.1 | 36 | 50 min | 43 min | −7 min |
| 2 | 31.8 | 31.7 | 36.3 | 1 h 15 min | 1 h 26 min | +11 min |
| 3 | 32.5 | 31.9 | 37.5 | 2 h 15 min | 1 h 13 min | −1 h 2 min |
| 4 | 30 | 29.8 | 36.3 | 2 h 5 min | 2 h 29 min | +24 min |
| 5 | 28.7 | 28.3 | 37 | 2 h 30 min | 3 h 28 min | +58 min |
| 6 | 32.3 | 31.8 | 37 | 1 h 10 min | 1 h 17 min | +7 min |
| 7 | 29.9 | 29.3 | 36.5 | 2 h 30 min | 2 h 40 min | +10 min |
| 8 | 30.4 | 30.1 | 36.5 | 2 h | 2 h 16 min | +16 min |
| 9 | 33.7 | 33.7 | 35.9 | 30 min | 32 min | +2 min |
| 10 | 32.1 | 31.9 | 38.1 | 1 h 30 min | 1 h 19 min | −11 min |
| 11 | 29.5 | 30 | 36 | 2 h 30 min | 2 h 35 min | +5 min |
| 12 | 30.1 | 30.2 | 36.7 | 1 h | 2 h 20 min | +1 h 20 min |
| 13 | 32.3 | 32.5 | 36.8 | 1 h 10 min | 1 h 7 min | −3 min |
| 14 | 29.8 | 29.7 | 36.5 | 2 h | 2 h 35 min | +35 min |
| 15 | 30.1 | 30.1 | 36 | 1 h 50 min | 2 h 22 min | +32 min |
| 16 | 30.5 | 30.5 | 36 | 2 h | 2 h 7 min | +7 min |
| 17 | 29.7 | 30 | 36.2 | 3 h | 2 h 31 min | +31 min |
| 18 | 31.6 | 31.7 | 38 | 2 h | 1 h 29 min | −31 min |
| 19 | 31.1 | 31.1 | 37 | 3 h 20 min | 3 h 55 min | +35 min |
| 20 | 32.6 | 32.6 | 37.5 | 1 h | 1 h 1 min | +1 min |
| 21 | 30.7 | 30.6 | 37 | 2 h 30 min | 2 h 2 min | −28 min |
| 21′ | 29.8 | 29.8 | 36.5 | 3 h 30 min | 2 h 33 min | −57 min |
| 22 | 31.8 | 31.6 | 35.5 | 1 h 30 min | 1 h 28 min | −2 min |
| 22′ | 29.6 | 29.5 | 35 | 2 h 30 min | 2 h 43 min | +13 min |
| 23 | 30.7 | 30.7 | 35.5 | 1 h 45 min | 2 h 1 min | +16 min |
| 23′ | 30.2 | 30.1 | 35.1 | 2 h 45 min | 2 h 20 min | −25 min |
| 24 | 30.9 | 30.7 | 36.7 | 1 h 30 min | 1 h 57 min | +27 min |
| 24′ | 30 | 29.9 | 36.4 | 2 h 30 min | 2 h 28 min | −2 min |
| 25 | 31.1 | 31.1 | 37 | 2 h 30 min | 2 h 47 min | +17 min |
| 25′ | 29.9 | 29.8 | 36.1 | 3 h 30 min | 2 h 31 min | −59 min |
| 26 | 33.1 | 33.3 | 37.2 | 1 h | 45 min | −15 min |
| 26′ | 30.8 | 30.9 | 36.9 | 2 h | 2 h 55 min | +55 min |
| 27 | 31.1 | 31.2 | 36 | 2 h | 1 h 46 min | −14 min |
| 27′ | 29.7 | 29.7 | 35.6 | 3 h | 2 h 37 min | −23 min |
| 28 | 32.7 | 32.4 | 36.5 | 1 h | 1 h 2 min | +2 min |
| 28′ | 31.3 | 30.9 | 36.1 | 2 h | 1 h 47 min | −13 min |
| 29 | 28.8 | 28.6 | 34 | 2 h 15 min | 3 h 19 min | +1 h 14 min |
| 29′ | 27.7 | 27.4 | 33.3 | 3 h 15 min | 4 h 15 min | +1 h |
| 30 | 33.7 | 33.5 | 38 | 1 h | 34 min | −26 min |
| 30′ | 32.2 | 32 | 38 | 2 h | 1 h 16 min | −44 min |

$$\mathrm{RMSE} = \sqrt{\frac{\sum_i (PMI_{act,i} - PMI_{pred,i})^2}{N}} = 0.51$$

and $k_c = -0.2\,\mathrm{h}^{-1}$, where RMSE = 0.51 h. The 95% confidence interval for the current model of PMI estimation can be presented as ± 1.96 × RMSE = ± 1 h, reaching the same value as in the previous study for different coefficients $k_c$ and $T_0$. [11].

Therefore, the transformation of Eq. (1) and its completion with the numerical value of $k_c$ = -0.2 $\mathrm{h}^{-1}$ and $T_0$ = 35 °C gives:

$$t = -\frac{\ln\left(\frac{T - T_a}{35 - T_a}\right)}{0.2} \tag{2}$$

The results of temperature measurements after death, and the actual and calculated (predicted) PMI for 30 cases (40 records), are presented in Table 1. In all of the 30 studied cases the temperatures were measured in both eyeballs and a mean was taken for the calculations.

Fig. 2 shows graphically the correlation between the actual PMI and the corresponding values calculated (predicted) from Eq. (2).

The mathematical calculations of the acquired data with the use of Eq. (2) have shown that the mean PMI estimation error for all 30 cases in the current study was ± 24 min (0.4 h) during post-mortem intervals of up to 3 h 30 min, while the method's accuracy in the 95% confidence interval during this time can be defined as ± 1 h. The highest error was 1 h 20 min, 1 h 2 min and 1 h in three of all the 30 cases studied, while for the remaining 27 cases it was less than 1 h.

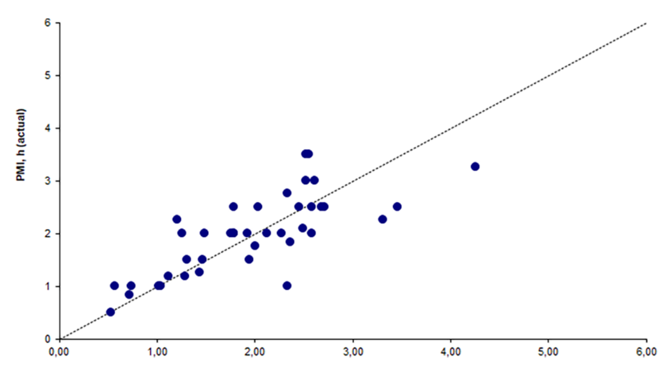


**Fig. 2.** Values of actual PMI versus predicted by Eq. (2) in 30 individuals (40 measurements).

In our previous studies the hypothesis of possible influence of the amount of hair was raised as in two cases with bald head the cooling of the eyeball seemed to be slightly accelerated [11]. However in the actual study in all the cases the hair length was similar (short to medium), so the possible influence of hair on eyeball cooling could neither be confirmed nor excluded. This issue may be a challenge for the future studies.

**Table 2**
Examples of PMI calculations using Henssge method based on rectal temperature measurements in the early post mortem period in standard conditions: room temperature, without corrective factor.

| Rectal temperature, °C | Ambient temperature, °C | Body mass, kg | PMI calculated using Henssge method [15] |
|---|---|---|---|
| 37 | 22 | 70 | 1 h 15 min ± 2.8 h |
| 37 | 22 | 90 | 1 h 36 min ± 2.8 h |
| 36 | 22 | 70 | 3 h 31 min ± 2.8 h |
| 36 | 22 | 90 | 4 h 28 min ± 2.8 h |

## 4. Conclusions

Thanks to the opportunity of acquiring data from a new series of cases, with precisely known TOD and a stable ambient temperature in the study room, the previously presented method of TOD estimation based on post-mortem eyeball temperature measurements in the early post-mortem period could be improved and become an additional method to the Henssge method based on rectal temperature measurements. Again, it should be stressed that such an accurate estimation of TOD in the early post-mortem period could not have been achieved if only rectal temperature data had been relied upon, simply because of the several-hour-long plateau effect. As one can see from Table 1, in most of the 30 studied cases, the rectal temperature during the recording period of a few hours was still higher than 36 °C, which often reflects a living individual's body temperature. Therefore, the only information concerning TOD in most of the above cases when the rectal temperature was around 36–37 °C, obtained using a Henssge nomogram, the most common method among forensic pathologists, based on rectal temperature measurement, was that the moment of death could be placed within at least a 5-h-wide time frame – as can be seen on various examples presented in Table 2 [15]. Table 2 presents exemplary cases (for standard body weights) as the limitation of the actual study was lack of body weighing in patients who died in the Intensive Therapy Unit if autopsy was not performed. In the majority of the cases presented in this paper the rigor mortis was absent and the lividity was absent or scant, so even using the compound method integrating the rectal temperature measurement and non-temperature based methods, one can only say that the time which passed from the moment of death can be placed between 0 and 3 h. However, the presented study clearly confirms that in the later phase of body cooling the Henssge method based on single rectal temperature measurement is of no questionable value, as well as is the compound method [1–4].

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