Check for updates

Technical report | Технический отчет
DOI: https://doi.org/10.35693/SIM624827

A postmortem interval estimation by cranioencephalic thermometry at a single discrete decrease in ambient temperature

German V. Nedugov

Samara State Medical University (Samara, Russia)

Abstract

Aim – to develop an estimation method and a computer program for determining the postmortem interval (PMI) by cranioencephalic temperature (CT) of a corpse under conditions of cooling with a single discrete decrease in ambient temperature.

Material and methods. We performed an analytical and finite element modeling of CT dynamics at a single discrete decrease in ambient temperature.

Results. A mathematical model has been developed for determining the PMI and the uncertainty of its estimates at a single discrete decrease in the ambient temperature. The constants' values of the model equation and their variances were determined on the basis of finite element modeling of CT dynamics under the specified cooling conditions. The computational algorithm of the specified method for determining PMI and limitations of its use were implemented in the Warm Bodies DSC program written on C#.

Conclusion. We can recommend using the developed method and software in forensic medicine to determine the PMI at a single discrete decrease in ambient temperature.

Keywords: corpse cooling, postmortem interval, cranioencephalic temperature.

Conflict of interest: nothing to disclose.

Citation
Nedugov G.V. **A postmortem interval estimation by cranioencephalic thermometry at a single discrete decrease in ambient temperature.** *Science and Innovations in Medicine.* 2025;10(3):218-223. DOI: https://doi.org/10.35693/SIM624827

Information about author
German V. Nedugov – Dr. Sci. (Medicine), Associate professor, Head of the Department of Forensic Medicine.
ORCID: 0000-0002-7380-3766
E-mail: nedugovh@mail.ru

Received: 19.12.2023
Accepted: 09.03.2024
Published: 17.05.2024

Оценка давности наступления смерти методом краниоэнцефальной термометрии при однократном дискретном понижении внешней температуры

Г.В. Недугов

ФГБОУ ВО «Самарский государственный медицинский университет» Минздрава России (Самара, Россия)

Аннотация

Цель – разработка реализованного в формате компьютерной программы метода определения ДНС по КТ трупа в условиях его охлаждения при однократном дискретном понижении внешней температуры.

Материал и методы. Выполнено аналитическое и конечно-элементное моделирование динамики КТ при однократном дискретном понижении внешней температуры.

Результаты. Разработана математическая модель определения ДНС и неопределенности ее оценок при однократном дискретном понижении внешней температуры. Значения констант модельного уравнения и их дисперсий определены путем конечно-элементного моделирования динамики КТ в указанных условиях охлаждения. Вычислительный алгоритм данного метода определения ДНС и противопоказания к его применению реализованы на языке C# в виде программы Warm Bodies DSC.

Выводы. Разработанный метод и реализующее его приложение рекомендуются к использованию в судебно-медицинской практике для определения ДНС при однократном дискретном понижении внешней температуры.

Ключевые слова: охлаждение трупа, давность наступления смерти, краниоэнцефальная температура.

Конфликт интересов: не заявлен.

Для цитирования:
Недугов Г.В. **Оценка давности наступления смерти методом краниоэнцефальной термометрии при однократном дискретном понижении внешней температуры.** *Наука и инновации в медицине.* 2025;10(3):218-223.
DOI: https://doi.org/10.35693/SIM624827

Сведения об авторе
Недугов Герман Владимирович – д-р мед. наук, доцент, заведующий кафедрой судебной медицины.
ORCID: 0000-0002-7380-3766
E-mail: nedugovh@mail.ru

Список сокращений
ДНС – давность наступления смерти;
КТ – краниоэнцефальная температура.

Получено: 19.12.2023
Одобрено: 09.03.2024
Опубликовано: 17.05.2024

INTRODUCTION

The ‘gold standard’ of estimating the postmortem interval (PMI) in the early postmortem period remains C. Henssge’s method, the use of which requires a single measurement of rectal or cranioencephalic temperature (CT) [1–5]. This method is based on the phenomenological law of deep tissue cooling in corpses at constant ambient temperature, proposed in 1962 by researchers T.K. Marshall and F.E. Hoare, which takes the form of a transcendental equation:

$$\frac{T-T_a}{T_0-T_a}=\frac{p}{p-k}e^{-kt}-\frac{k}{p-k}e^{-pt}, \quad (1)$$

where T – current core body temperature of the corpse, °C; T_a – ambient temperature, °C; $T0$ – initial body temperature at the diagnostic point at the moment of death, °C; k – cooling constant, h^{-1}; p – temperature plateau constant, h^{-1}; t – TSD, h [6].

In his modification of the equation (1) C. Henssge used the analysis of a vast amount of empirical data to establish linear dependencies of the temperature plateau constant from the cooling constant, as well as mean statistical data of the latter in various conditions of cooling of the dead body [7, 8]. The most critical condition for the accuracy of this method, which significantly limits its practical application, is the constancy of ambient temperature. This specific circumstance has prompted a series of studies focused on adapting Henssge’s method to variable ambient temperature conditions [9–11].

One of the forensically relevant patterns of ambient temperature variation in medico-legal practice is its single discrete decrease, referring to a one-time reduction in external temperature while maintaining constant temperature thereafter [12]. This generic change in the cooling conditions is usually seen in the corpse thermometry after it had been relocated from the place of discovery to a storage vault with different temperature conditions. In such situations, the ambient temperature before and after relocation or the corpse, time after the relocation before the thermometry, and the results of the thermometry are usually known [9]. After experimenting on manikins, L. Althaus and C. Henssge developed a phenomenological model of determining the PMI in the specific conditions of cooling based on the equation (1) and data of rectal thermometry [9]. This model was later optimized and implemented as a computer program. Apart from the measurement of changes in the temperature conditions, it considered changes in other conditions of cooling of the dead body, namely, the properties of its clothes and bed, as well as status of wind of water flow [12].

On the whole, the data obtained provided a solution for determination of the PMI by a single discrete decrease in the ambient temperature by rectal thermometry of the corpse. At the same time, in order to obtain valid evaluations of PMI based on rectal thermometry of the corpse, the initial ambient temperature conditions with its discrete decrease should not exceed 23.2 °C [9, 13]. For that reason, the approach proposed by L. Althaus and C. Henssge is not applicable if the initial ambient temperature is above the given threshold, which significantly limits the application of the method.

Unlike the case of rectal temperature, the dynamics of CT is characterized by lack of influence of external temperature on the linkage between the constants of thermal plateau and cooling, which is expressed as the following ratio for this diagnostic point:

$$p=8{,}425k. \quad (2)$$

Moreover, evaluation of PMI by cranioencephalic thermometry does not require measurement of the mass of the corpse [7, 8, 13]. Notwithstanding these advantages, no technologies of PMI evaluation with single discrete decrease of ambient temperature by cranioencephalic thermometry of the corpse have been proposed. At the same time, the forensic expert practice requires such technologies whose calculation algorithms are implemented as computer programs.

AIM

To develop an estimation method and a computer program for determining the postmortem interval (PMI) by cranioencephalic temperature (CT) of a corpse under conditions of cooling with a single discrete decrease in ambient temperature.

MATERIAL AND METHODS

The methodological design of the study is to develop a phenomenological model of PMI determination with single discrete decrease of ambient temperature based on finite element modeling of CT dynamics with the given conditions of corpse cooling, the calculation algorithm of the model to be implemented as a computer program.

The mathematical model of the corpse core cooling involved two periods, the initial and the final, representing periods before and after changes in the cooling conditions, respectively. The model of CT dynamics in the final period of corpse cooling was based on the equation (1) with respect to linear correlation (2) of its constants. The value range of the constants in the equation (1) was determined by numeric search of solution of the Marshall-Hoare system of nonlinear equations (SNE) for double thermometry of the corpse:

$$\begin{cases} T_{0_2}=\dfrac{\left(T_1-T_{a_2}\right)\left(p-k\right)}{pe^{-kt_2}-ke^{-pt_2}}, \\ T_{0_2}=\dfrac{\left(T_2-T_{a_2}\right)\left(p-k\right)}{pe^{-k(t_2+\Delta t)}-ke^{-p(t_2+\Delta t)}}, \end{cases} \quad (3)$$

where Ta_2 – final ambient temperature, °C; t_2 – duration of the final period of cooling, h; T_1 – CT in the first thermometry of the corpse in the end of t_2 period, °C; T_2 – CT in the second thermometry of the corpse, °C; Δ_t – time between the thermometries of the corpse, h (**Fig. 1**).

To that end, roots of the equation

$$\left(T_1-T_{a_2}\right)\left(pe^{-k(t_2+\Delta t)}-ke^{-p(t_2+\Delta t)}\right)-\\-\left(T_2-T_{a_2}\right)\left(pe^{-kt_2}-ke^{-pt_2}\right)=0, \quad (4)$$

were found that would meet the various conditions of the specific type of cooling. The nonlinear optimization of the functions (4) obtained from the SNE (3) with constants k and p serving as variables was performed using the generalized reduced gradient method implemented in the "Solver" add-in of the Microsoft Office Excel 2016 spreadsheet processor.

The values of other indicators of the SNE (3) were found by computer modeling by finite element method for the thermal field of the head in the conditions of convective heat exchange with the heat transfer factor of 6 W/(m²·K), for various combinations of the initial and final cooling periods in the absence of internal and external heat sources. The borderline values of parameters of these cooling conditions were as follows: initial period, 10–35 °C, final period, 4–11 °C, difference between the initial and final ambient temperatures was 2–26 °C; duration of the initial cooling period, 1–21 h, duration of the final cooling period, 1–10 h; the interval between the first and second thermometry of the corpse was 0.5–2 hours. The discretization step for ambient temperatures was 1°C, cooling period durations, 1 h, and time intervals between corpse thermometry measurements were 0.5 h. In total, 148 non-degenerate solutions to the SNEs (3) were found based on the generated data.

For the purposes of computer modeling of postmortem CT dynamics, a two-dimensional finite-element model of the cerebral head region was used. It was designed as a quadrant with 98 mm radius comprising uniformly distributed homogeneous layers: cutaneous-aponeurotic flap (5 mm), cranial vault bones (5 mm), subarachnoid space cerebrospinal fluid (2 mm), and brain tissue (86 mm). The thermo-physical parameters of these biological tissues, procedures for establishing initial and postmortem temperature fields in the computational domain, and validation of the finite-element model were previously detailed in our work [14]. CT was defined as the temperature at the point with zero radial coordinate.

The finite element model of the postmortem thermal field of the head was constructed using the free version of ELCUT 6.5 (https://elcut.ru/free_soft_r.htm). The remaining calculation procedures were performed in Microsoft Excel (Office 2016 software suite). The mathematical analysis was performed in the free web application WolframAlpha (https://www.wolframalpha.com). The code of the program calculating PMI and error of the obtained estimates was written in C# using the free version of Microsoft Visual Studio (https://visualstudio.microsoft.com/ru/downloads).

RESULTS

In the initial cooling period, the CT dynamics progresses in accordance with equation (1) with constant values established by C. Henssge [7, 8, 13]. Provided that the CT value as of the moment of decrease of ambient temperature is available, it is possible to determine the duration of the initial cooling period, which represents the root of the implicitly defined equation

$$1{,}135e^{-0{,}127t_1} - 0{,}135e^{-1{,}07t_1} - \frac{T_{0_2} - T_{a_1}}{T_{0_1} - T_{a_1}} = 0, \qquad (5)$$

where t_1 – duration of the initial cooling period, h; T_{0_2} – CT at the moment of change of cooling regimes, °C; Ta_1 – initial ambient temperature, °C; T_{0_1} – initial CT as per recommendations of C. Henssge, taken to be 37.2 °C (**Fig. 1**).

Thus, the task of determining the PMI in the given conditions is reduced to the task of determining the CT at the moment of change of thermal modes of cooling.

Computer simulation of cooling under the considered conditions showed that during the final cooling period, CT dynamics also follow law (1), but with unknown individual values of cooling constants and temperature plateau.

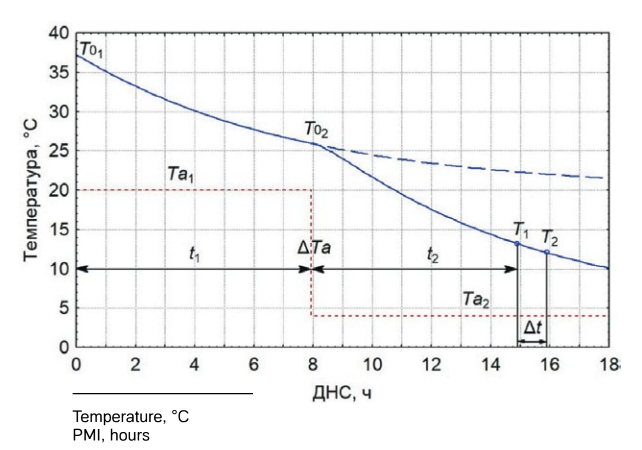

Figure 1. *Dynamics of cranioencephalic temperature on the example 1 (solid blue line). The red dashed line marks the dynamics of ambient temperature. The dashed blue line shows the conditional dynamics of cranioencephalic temperature in the absence of a change in cooling modes.*

Рисунок 1. *Динамика КТ для данных из примера 1 (сплошная синяя линия). Красной штриховой линией маркирована динамика внешней температуры. Штриховой синей линией показана условная динамика КТ при отсутствии смены режима охлаждения.*

To determine the ranges of constants k and p using the generalized reduced gradient method, a search was performed for solutions of equation (4) variants generated based on the finite-element model that satisfy given boundary conditions under various regimes of single discrete decreases in ambient temperature. This search showed that the average value of the k constant is 0.135 h^{-1}, and its dispersion, maximum in the first two hours of the final period of cooling, then drastically decreases decaying to zero after five hours (**Fig. 2**). The maximum deviation of the cooling constant from its average value in the period of 3 to 10 hours after the decrease of ambient temperature reached 0.007 h^{-1}.

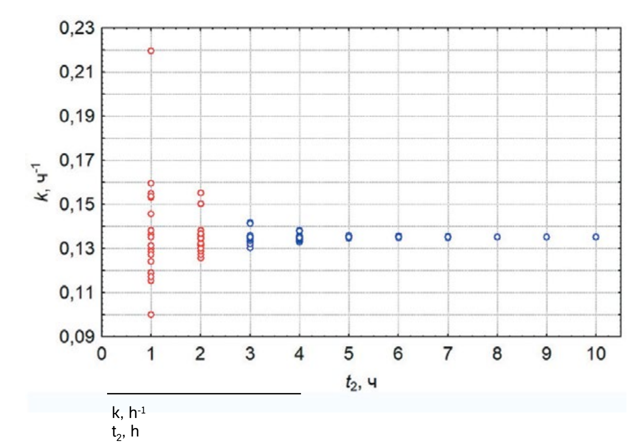

Figure 2. *Dependence of the cooling constant on the duration of the final cooling period according to finite element modeling of corpse cooling under various modes of a single discrete decrease in ambient temperature. The values of k at t_2 < 3 h and ΔTa < 6 °C are marked in red.*

Рисунок 2. *Зависимость константы охлаждения от продолжительности финального периода охлаждения по данным конечно-элементного моделирования охлаждения трупа при различных режимах однократного дискретного понижения внешней температуры. Красным маркированы значения k при t_2 < 3 ч и ΔTa < 6 °C.*

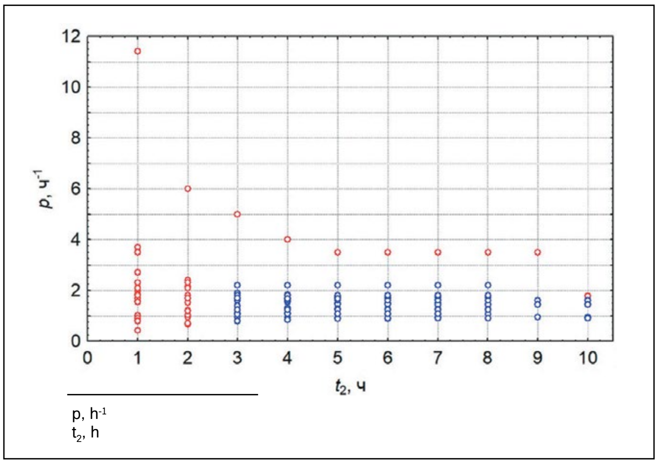

Figure 3. *The dependence of the temperature plateau constant on the duration of the final cooling period according to finite element modeling of corpse cooling under various modes of a single discrete decrease in ambient temperature. The values of p at t_2 < 3 h and ΔTa < 6 °C are marked in red.*

Рисунок 3. *Зависимость константы температурного плато от продолжительности финального периода охлаждения по данным конечно-элементного моделирования охлаждения трупа при различных режимах однократного дискретного понижения внешней температуры. Красным маркированы значения p при t_2 < 3 ч и ΔTa < 6 °C.*

The values of the p constant in the first two hours of the final cooling period, as well as with the difference ΔT_a of the initial and the final temperatures below 6 °C also demonstrated marked dispersion, whereas in other options of the studies cooling conditions the distribution of values of the constant was uniform with the average value being 1.4 h^{-1} and maximum deviation from the average at 0.8 h^{-1} (**Fig. 3**).

The obtained data allow using the established average values of both constants when determining CT at the moment of ambient temperature change via any of the SNEs (3). It is preferable to use the first equation for this purpose, as it contains fewer arguments and does not require repeated corpse thermometry for calculations. After calculating CT at the moment of ambient temperature shifts, the duration of the initial cooling period is determined by formula (5). Thus, the sought PMI represents the sum of the initial and final cooling periods: $t=t_2+t_1$, where t – PMI, h.

Example 1. The corpse was discovered in a room with an air temperature of 20.0 °C, then transported to the morgue and placed in a refrigeration chamber at 4.1 °C, where cranioencephalic thermometry was performed 7 hours after discovery. The CT measured 14.0 °C. It is necessary to determine PMI at the time of corpse thermometry.

As per SNE (3), at the moment of ambient temperature change the corpse CT was

$$T_{0_2} = \frac{(14-4{,}1)(1{,}4-0{,}135)}{1{,}4e^{-0{,}135\cdot 7} - 0{,}135e^{-1{,}4\cdot 7}} = 27{,}115 \ \ °C.$$

Using the obtained CT value in the equation (5), we obtain the expression

$$1{,}135e^{-0{,}127t_1} - 0{,}135e^{-1{,}07t_1} - \frac{27{,}115-20}{37{,}2-20} = 0\ ,$$

from which we calculate t_1 = 7.95 h. Therefore, the PMI at the moment of the corpse thermometry is

t = 7,95+7=14,95 h.

Due to the use of average values of the SNEs (3) constants, CT estimates obtained by the described method will inherently contain errors. The magnitude of these errors will be further influenced by inaccuracies in corpse thermometry and ambient temperature measurement, duration measurement errors of the final cooling period. According to the first SNE (3), the CT at the moment of cooling regime shifts can be treated as a function of

$$T_{0_2}=F(k, p, t_2, T_{a_2}, T_1) \qquad (6)$$

5 random variables. Assuming there are no mutual correlation among the errors of the arguments of this function, the variance of CT estimation errors is determined from the equation

$$\sigma^2_{T_{0_2}} = \left(\frac{\partial F}{\partial k}\right)^2 \sigma_k^2 + \left(\frac{\partial F}{\partial p}\right)^2 \sigma_p^2 + \left(\frac{\partial F}{\partial t_2}\right)^2 \sigma_{t_2}^2 + \left(\frac{\partial F}{\partial T_{a_2}}\right)^2 \sigma^2_{T_{a_2}} + \left(\frac{\partial F}{\partial T_1}\right)^2 \sigma^2_{T_1}\ , \qquad (7)$$

where σ^2 – error dispersion, and F is the function (6). With no information about standard deviations of errors being available, they should be set equal to one-third of the maximum permissible error of the corresponding parameter.

The uncertainty of estimates of the initial period t_1 according to data [12] is

$$\sigma_{t_1} = 2{,}0889e^{-1{,}1411Q}\ ,$$

where Q – non-dimensional temperature, in this case calculated as

$$Q = \frac{T_{0_2} - T_{a_1}}{T_{0_1} - T_{a_1}}\ .$$

The total variance of PMI estimation errors equals the sum of variance in initial cooling period duration errors, variance in final cooling period duration errors, and variance in CT estimation errors at the moment of ambient temperature regime shifts:

$$\sigma_t^2 = \sigma_{t_1}^2 + \sigma_{t_2}^2 + \left(\frac{\partial f(t)}{\partial T_{0_2}}\right)^2 \sigma^2_{T_{0_2}}\ ,$$

where $f(t)$ – implied function (5), the partial derivative of which for T02 is determined by the equation

$$\frac{\partial f(t)}{\partial T_{0_2}} = \left[(T_{a_1} - T_0)\left(0{,}14445e^{-1{,}07t_1} - 0{,}144145e^{-0{,}127t_1}\right)\right]^{-1}\ .$$

Knowing the error variance, one can calculate the tolerant interval of PMI:

$$PMI = t \pm \sigma_t \cdot z_{1-\alpha}\ ,$$

where t – PMI estimate, h; z – standard normal variable; α – level of significance..

Example 2. Determine the 95% tolerant interval of PMI for the data from Example 1, taking the absolute threshold errors of corpse thermometry and ambient temperature measurement as 0.1 °C and the final cooling period as 20 minutes (0.333 h).

x indicator	Value	Δx	σ	$\frac{\partial F}{\partial x}$	Product of squares
T_1, °C	14	0,1	0,033333	2,324753	0,006004972
Ta_2, °C	4,1	0,1	0,033333	-1,32475	0,001949966
t_2, ч	7	0,333333	0,111111	3,106631	0,119150105
k, $ч^{-1}$	0,135	0,007	0,002333	142,9162	0,111203002
p, $ч^{-1}$	1,4	0,8	0,266667	1,751952	0,218263764

Table 1. *Intermediate calculations of the cranioencephalic temperature error at the time of changing the temperature regimes of cooling the corpse*

Таблица 1. *Промежуточные расчеты погрешности КТ в момент смены температурных режимов охлаждения трупа*

The results of preliminary calculations of CT error variance at the time of cooling temperature shifts are shown in **Table 1**.

Summing up the products of squares, we find that the CT variance is 0.4566.

Since

$$Q = \frac{27{,}115 - 20}{37{,}2 - 20} = 0{,}4137,$$

then

$$\sigma_{t_1} = 2{,}0889 e^{-1{,}1411 \cdot 0{,}4137} = 1{,}3029.$$

Therefore

$$\sigma_t = \sqrt{1{,}3029^2 + 0{,}1111^2 + 0{,}4566\left[(20 - 27{,}115)\right.} \\ \overline{\left.\left(0{,}14445 e^{-1{,}07 \cdot 7{,}95} - 0{,}144145 e^{-0{,}127 \cdot 7{,}95}\right)\right]^{-2}} = 1{,}51 \text{ ч.}$$

Multiplying the value of the standard normal variable of 1.960 by the standard PMI error variance, we calculate the 95% tolerant interval of the latter:

PMI=14.95±2.95 h.

The described computational algorithm was formalized in C# within the computer program Warm Bodies SDC (Certificate of State Registration of Computer Program No. 2023687943). Based on the proposed mathematical model, the application calculates PMI from corpse CT when there is a single discrete decrease in constant ambient temperature by 6 °C or more and a final cooling period duration of 3 to 10 hours. In addition to point estimates, the program determines two-sided interval estimates of PMI for the required confidence probability level. The calculated error magnitude includes inaccuracies arising from potential deviations of individual cooling conditions from statistical averages, as well as measurement errors of input parameters.

The maximum errors for the latter are set at 0.1°C for temperature parameters and 5% for the duration of the final cooling period. The application calculates the duration of the initial cooling period using Newton's iterative method. When degenerate cooling scenarios are detected, the program halts calculations and displays a corresponding warning window. To operate the program, the user must input the result of the single-time corpse CT measurement, initial and final ambient temperatures, time interval between the ambient temperature decrease and body thermometry, initial CT, and permissible error probability.

DISCUSSION

The computer modeling conducted in this study demonstrated that CT dynamics following a single discrete decrease in ambient temperature conform to the Marshall-Hoare equation (1). This cooling pattern under such conditions appears universal for all deep corpse tissues, as L. Althaus and C. Henssge observed the same phenomenon when studying rectal temperature dynamics [9]. However, due to the impossibility of establishing individual constants for equation (1) during the final cooling phase, these authors replaced equation (1) with their own empirical expression when developing their PMI determination method.

Unlike the approach of L. Althaus and C. Henssge, the method to determine CT at the moment of cooling temperature shifts suggested within this study uses the original Marshall-Hoare equation with the average values of cooling and thermal plateau constants obtained by computer modeling of a wider range of different variants of discrete decrease of ambient temperature. Additionally, the method provides for calculating uncertainty both in estimates of BT at the moment of cooling regime changes and in final estimates of PMI, based on variances of the constants of equation (1) and measurement errors of temperature and time parameters.

The use of the developed method may be limited due to possible discrepancies between real cooling conditions and those modeled in the computer experiment. The reasons for potential discrepancies include: 1) heat transfer through conduction when the cooling body part contacts other physical objects; 2) convection under non-standard conditions with different heat transfer coefficients; 3) thermo-physical properties of tissues in the cooling body region differing from model parameters.

However, the selected body part for the modeling of cooling (the head) demonstrates the highest resistance to the listed factors affecting PMI determination accuracy. This is because the shape of the head closely approximates a sphere, which has only one point of contact with a tangential plane. This circumstance allows neglecting heat conduction processes when the corpse's head rests on a flat surface. The anatomical structure of the head and its modeled tissue layers exhibits minimal variability. Additionally, the constants of equation (1) for non-standard cooling scenarios (presence of headwear, strong wind, liquid contact) can be refined through future finite-element modeling of corresponding cooling conditions. [15–17].

The developed method is contraindicated for use when the duration of the final cooling period is less than 3 hours and when the difference between initial and final ambient temperature regimes is less than 6°C. In the first case, the cooling process does not exhibit distinct exponential and temperature equilibration phases. In the second case, the temperature plateau phase is absent. These circumstances naturally lead to a mismatch between mathematical model (1) and actual cooling conditions, resulting in increased variance of equation (1) constants and greater errors in PMI estimates. These contraindications are easily manageable in practice. In the first case, it is sufficient to perform corpse thermometry after a longer period following its transfer to different cooling conditions. In the second case, it is advisable to consider the ambient temperature as constant in calculations, equal to the average value of the sum of initial and final ambient temperatures, with a maximum measurement error of 3°C.

The contraindications also include limitations inherent to all thermometric PMI determination methods based on C. Henssge's modifications of equation (1), e.g., solar radiation, significant fluctuations of ambient temperature during initial and final cooling periods, marked deviations from normothermic thanatogenesis [7, 8, 13].

CONCLUSIONS

1. A method has been developed for determining PMI and the errors of its estimates based on corpse CT under cooling conditions with a single discrete decrease in ambient temperature.

2. The computational algorithm of the proposed PMI determination method and contraindications for its use are implemented in the Warm Bodies DSC application program.

3. The developed method and the computer program implementing it are recommended for use in forensic expert practice for thermometric PMI determination during single discrete decreases in ambient temperature.

ADDITIONAL INFORMATION	ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ
Study funding. The study was the author's initiative without external funding.	***Источник финансирования.*** Работа выполнена по инициативе автора без привлечения финансирования.
Conflict of interest. The author declares that there are no obvious or potential conflicts of interest associated with the content of this article.	***Конфликт интересов.*** Автор декларирует отсутствие явных и потенциальных конфликтов интересов, связанных с содержанием настоящей статьи.

REFERENCES / ЛИТЕРАТУРА

1. Hubig M, Muggenthaler H, Mall G. Confidence intervals in temperature-based death time determination. *Leg Med (Tokyo)*. 2015;17(1):48-51. DOI: 10.1016/j.legalmed.2014.08.002
2. Schweitzer W, Thali MJ. Computationally approximated solution for the equation for Henssge's time of death estimation. *BMC Med Inform Decis Mak*. 2019;19(1):201. DOI: 10.1186/s12911-019-0920-y
3. Potente S, Henneicke L, Schmidt P. Prism - A novel approach to dead body cooling and its parameters. *Forensic Sci Int*. 2021;325:110870. DOI: 10.1016/j.forsciint.2021.110870
4. Laplace K, Baccino E, Peyron PA. Estimation of the time since death based on body cooling: a comparative study of four temperature-based methods. *Int J Legal Med*. 2021;135(6):2479-2487. DOI: 10.1007/s00414-021-02635-7
5. Wei T, Abraham J, Wang Y. Comment on the Marshall-Hoare-Henssge model for estimating the time since death. *J Forensic Sci*. 2023;68(2):676-681. DOI: 10.1111/1556-4029.15218
6. Marshall TK, Hoare FE. Estimating the time of death. The rectal cooling after death and its mathematical expression. *J Forensic Sci*. 1962;7(1):56-81.
7. Henssge C. Death time estimation in case work. I. The rectal temperature time of death nomogram. *Forensic Sci Int*. 1988;38(3-4):209-236. DOI: 10.1016/0379-0738(88)90168-5
8. Henssge C. Rectal temperature time of death nomogram: dependence of corrective factors on the body weight under stronger thermic insulation conditions. *Forensic Sci Int*. 1992;54(1):51-66. DOI: 10.1016/0379-0738(92)90080-G
9. Althaus L, Henssge C. Rectal temperature time of death nomogram: sudden change of ambient temperature. *Forensic Sci Int*. 1999;99(3):171-178. DOI: 10.1016/s0379-0738(98)00188-1
10. Bisegna P, Henssge C, Althaus L, Giusti G. Estimation of the time since death: sudden increase of ambient temperature. *Forensic Sci Int*. 2008;176(2-3):196-199. DOI: 10.1016/j.forsciint.2007.09.007
11. Nedugov GV. Double exponential model of corpse cooling under conditions of linearly varying ambient temperature. *Russian Journal of Forensic Medicine*. 2021;7(4):19-28. (In Russ.). [Недугов Г.В. Двойная экспоненциальная модель охлаждения трупа в условиях линейно изменяющейся внешней температуры. *Судебная медицина*. 2021;7(4):19-28]. DOI: 10.17816/fm429
12. Nedugov GV. New computer technologies to determine postmortem interval by the Henssge method. *Russian Journal of Forensic Medicine*. 2021;7(3):152-158. (In Russ.). [Недугов Г.В. Новые компьютерные технологии определения давности наступления смерти по методу Henssge. *Судебная медицина*. 2021;7(3):152-158]. DOI: 10.17816/fm406
13. Henssge C, Madea B. Estimation of the time since death in the early post-mortem period. *Forensic Sci Int*. 2004;144(2-3):167-75. DOI: 10.1016/j.forsciint.2004.04.051
14. Nedugov GV. Estimation of the postmortem interval by the method of finite element modeling of postmortem heat transfer in human head. *Science & Innovations in Medicine*. 2022;7(3):179-185. [Недугов Г.В. Оценка давности наступления смерти методом конечно-элементного моделирования посмертного теплообмена головы. *Наука и инновации в медицине*. 2022;7(3):179-185]. DOI: 10.35693/2500-1388-2022-7-3-179-185
15. Schenkl S, Muggenthaler H, Hubig M, et al. Automatic CT-based finite element model generation for temperature-based death time estimation: feasibility study and sensitivity analysis. *Int J Legal Med*. 2017;131(3):699-712. DOI: 10.1007/s00414-016-1523-0
16. Subramaniam JS, Hubig M, Muggenthaler H, et al. Sensitivity of temperature-based time since death estimation on measurement location. *Int J Legal Med*. 2023;137(6):1815-1837. DOI: 10.1007/s00414-023-03040-y
17. Ullrich J, Weiser M, Shanmugam Subramaniam J, et al. The impact of anatomy variation on temperature based time of death estimation. *Int J Legal Med*. 2023;137(5):1615-1627. DOI: 10.1007/s00414-023-03026-w