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Short communication

Time of death of victims found in cold water environment

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Abstract

Limited data is available on the application of post-mortem temperature methods to non-standard conditions, especially in problematic real life cases in which the body of the victim is found in cold water environment. Here we present our experience on two cases with known post-mortem times. A 14-year-old girl (rectal temperature 15.5 °C) was found assaulted and drowned after a rainy cold night (+5 °C) in wet clothing (four layers) at the bottom of a shallow ditch, lying in non-flowing water. The post-mortem time turned out to be 15–16 h. Four days later, at the same time in the morning, after a cold (±0 °C) night, a young man (rectal temperature 10.8 °C) was found drowned in a shallow cold drain (+4 °C) wearing similar clothing (four layers) and being exposed to almost similar environmental and weather conditions, except of flow (7.7 l/s or 0.3 m/s) in the drain. The post-mortem time was deduced to be 10–12 h. We tested the applicability of five practical methods to estimate time of death. Henssge's temperature–time of death nomogram method with correction factors was the most versatile and gave also most accurate results, although there is limited data on choosing of correction factors. In the first case, the right correction factor was close to 1.0 (recommended 1.1–1.2), suggesting that wet clothing acted like dry clothing in slowing down body cooling. In the second case, the right correction factor was between 0.3 and 0.5, similar to the recommended 0.35 for naked bodies in flowing water.

Keywords: Drowning; Estimation of time of death; Homicide; Methods; Post-mortem; Temperature; Wet clothing; Water environment

1. Introduction

Temperature-based methods, developed to estimate post-mortem time, are best suited for standard conditions [1–4] under which most of the methods seem to work quite well [4]. Serious difficulties can be expected when applying these methods for homicide investigation in cases in which the victim is found in water environment. Beside the need to control the effect of temperature gradient between rectal and environmental temperature, body size, clothing and moving air, the effect of water flow and influence of wet clothes should be considered. Comparatively little data is available to be applied in these cases. Moreover, field studies are a good indicator for the practical value of the methods to estimate the time of death, although these are nearly completely missing in the literature [5].

The original mathematical model (sigmoid cooling curve), describing the cooling of the body, was developed in 1962 by Marshall and Hoare [6], and a practical modification of the method has been published [7]. Of the several temperature methods available, all take advantage of this model, but many suffer from the lack of control of factors mentioned above. The temperature–time of death nomogram method published by Henssge [8] is based on a series of experimental research performed on dummies of varying sizes exposed to various conditions. The strength of the method is that the method uses experimental corrective factors to adapt the method for various environments and varying weights and clothing of the victim. The nomogram is handy and can be easily applied in practice. Very recently, another practical version of the temperature method based on Marshall's and Hoare's mathematical model – the Triple-Exponential Formula (TEF) method – has been developed [9–11].

In this paper, we tested the applicability of the methods above as well as of some other practical one-measurement based temperature methods suggested to be used in casework in two suspected homicide cases.

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2. Case reports

2.1. Homicide case

In November 14, 2000, a 14-year-old girl had been training at a local dancing school and was seen alive last at 19:07 h bicycling in the darkening evening from the town centre back to home, where she never arrived. Her parents began to search her a couple of hours later, first by themselves and then called the police. In the evening at the time of her disappearance, it started to rain heavily. Following an intensive search by the police, parents and friends, she was found dead next morning November 15 at 08:25 h lying in the bottom of a small ditch next to a bicycling path (Fig. 1(A)) about 300 m from the place she was last seen. Her bicycle was near her, thrown in the ditch. Her head was immersed up to the mouth in muddy water in a small water-filled pit in the ditch while the rest of the body was not immersed. The body had escaped detection although the place had been searched during the night by illuminating the path with the front-lights of a police car. There were only a few centimetres of water under the body. Her right hand was without clove. Her clothes were soaked after heavy rain during the night. The ditch may have contained more water during the rain. Following other technical investigations, rectal temperature (+15.5 °C) was measured at the scene at 11:00 h (Table 1). At the same time the environmental temperature was +6.5 °C. Rigor mortis was observed in all small and big joints and her mid body was stiff. Her clothing (underwear, T-shirt, blouse of a training suit, outdoor jacket, as well as outdoor pants made of viscose, socks and shoes) was completely wet. There were several bruises in the head and wrists compatible to beating and grasping of the wrists. The respiratory tract was filled with water and mud, and the death was due to drowning. No signs of sexual intercourse were found. DNA profiling from vaginal swabs disclosed no strange DNA. DNA profiling from the nails (collected together in one plastic bag) of the bare right hand showed incomplete DNA profile of some other person's DNA in addition to girl's DNA profile. It was impossible to know, when and under what situation the girl had caught strange DNA under the nails. Despite of that, the DNA profile was compared to some suspects DNA profile, but no match was found.

Table 1
Characteristics of the cases

	Homicide case	Accidental drowning case
Victim		
Age	14 year	33 year
Sex	Female	Male
Weight	53 kg	53 kg
Blood alcohol	0‰	2.3‰
Rectal temperature	15.5 °C	10.8 °C
Measurement time	11:00 h	10:10 h
Clothing	(All soaked)	(All soaked)
	Underwear	Underwear
	T-shirt	T-shirt
	Blouse of a straining suit	Collar shirt
	Outdoor jacket	Leather jacket
	Outdoor pants made of viscose	Blue jeans pants
	Socks	Socks
	Shoes	Shoes
Environment		
Temperature of air	+5.0 °C	±0 °C
Temperature of water	–	+4.0 °C
Amount of rain	8.2 mm	10.7 mm
Flow of water	None	0.3 m/s(7.7 l/s)
Speed of wind	2–3 m/s	1–2 m/s

The environmental temperature at the time of measurement of the rectal temperature had been +3 °C at the weather station 20 km south (Table 1). The temperature at the night had been higher around +5 °C. The night was weakly windy: at 20.00 h the speed of wind was 3 m/s and 3 h later at 23:00 h it was 2 m/s. During the night it rained 8.2 mm.

Despite questioning of nearly 1000 witnesses known to have walked, jogged or bicycled in the area during the evening and the following night, the case remained unsolved for 10 months. Then, upon second questioning, a young schoolboy, known to have been bicycling in the area, now admitted having confronted the girl on the bicycle path during the rain, turning his bicycle back and having assaulted her for reasons that remained unclear. He admitted throwing her in the ditch after hitting her in the head several times. The correct time of death

Fig. 1. (A)The body of the girl wearing wet clothes was found lying in the bottom of a small ditch next to a bicycling path. Her head was immersed up to the mouth in muddy water in a small water-filled pit in the ditch while the rest of the body was not immersed. (B) The body of the drowned man after being pulled out off water from a shallow flowing drain. His head and upper body had been immersed at the time of discovery.

was between 19:15 and 19:30 h giving a post-mortem time of 15.15–15.30 h. The DNA-profile of the perpetrator matched with the DNA profile of the small piece of tissue found under the girl's nail, suggesting that during the struggle the girl had succeeded in scraping the perpetrator.

2.2. Accidental drowning case

At the same time we were informed about a similar case of a young alcoholic man, who was found drowned under almost identical conditions a few days later. In the morning of November 19, 2000, at about the same time of the day (09:00 h), the body of a 33-year-old man was found drowned in a shallow drain, beneath a walk, a few kilometres from the centre of a small town in Southern Finland. The place was located in about the same latitude 200 km west and 30 km south of the homicide place. An empty bottle of strong alcohol was found near the body. The head and upper body of the victim were immersed in the shallow drain with depth of 12.5 cm (Fig. 1(B)). The diameter of the nearby concrete round culvert, through which the water was flowing below the walk, was 60 cm. The culvert was used in the calculations of the amount and speed of water. According to the report by the local water company, the speed of the flow is 7.7 l/s or 0.3 m/s with water level of 12.5 cm in the drain.

The case was first considered as a possible homicide case. At 09:40 h air temperature was 0 °C, water temperature was +4 °C, and the temperature of the skin of the victim was +4.4 °C. According to the records by nearby weather observation point the lowest temperature at 2 m height had been +1.9 °C and on the ground level −0.9 °C during the night. There had been showers during the night between 8 p.m. and 8 a.m. totalling 10.7 mm. His clothing (underwear, T-shirt, collar shirt, leather jacket, blue jeans, socks and shoes) was completely wet (Table 1). Rectal temperature was 10.8 °C measured at 10:10 h at the beginning of the medicolegal autopsy. Based on diatom analysis of lung tissue and forensic toxicological reports, the cause of death was considered to be drowning under the influence of alcohol (blood 2.3‰, urine 3.4‰) and cannabinoids (blood 49 μg/l). None of the findings indicated another person's involvement.

The victim had been seen alive last time 12 h before found dead in the previous evening while shortly after 9 p.m. trying to enter a local restaurant. The entrance was not permitted because of his heavy drunkenness. The walking distance between the restaurant and site of drowning was about 1.1 km. The maximal post-mortem time was therefore deduced to be about 10 h to the maximum of 12 h.

3. Methods

Henssge's temperature–time of death nomogram [8,12]. In the nomogram, the time since death can be read off in the semicircles of body weights with the aid of a line drawn through intersection of the pre-set diagonal line of the nomogram and a line connecting rectal temperature and ambient temperature. The effect of clothing, still/moving air/water is taken account by empirical correlation coefficients of the body weight. In standard situations the correction factor is 1.0. In non-flowing air/water the recommended correction factors for a body with two layers of wet clothing is 1.1 and for more that two wet thick layers or more it is 1.2. In circumstances of flowing air/water the recommended correction factor for a naked wet body is 0.35–0.7, for 1–2 thin layers of wet clothing it is also 0.7 and with 2 layers of clothing or more it is 0.9.

Triple-exponential formula (TEF) method by Al Alousi et al. [10]. In the practical Reference Chart-Ruler version of the method, the intercept R can be either calculated or read in the R scale corresponding to the crossing point of rectal temperature and environmental temperature. The time of death with 95% confidence intervals (error limits) can be read in the second chart at the crossing point of R intercept and rectal cooling curve.

Marshall published an easily calculable simplified modification [7] of the method by Marshall and Hoare [6], which is mathematically demanding and hardly applicable in casework. Marshall's formula is based on the finding that the time of the body to cool to 85% of the initial temperature difference between rectal temperature and environmental temperature is dependent on body size. According to Marshall, this occurs in 19 h in the case of thin body, in 28 h in normal sized body and in 41 h in the case of a fat body. First one has to calculate what the 85% difference in temperatures is. The formula is $T_{85\%} = 0.85 \times (37\,^{\circ}\mathrm{C} - T_{\mathrm{env}})$, where $T_{85\%}$ is 85% of the difference between body temperature and environment in the beginning of the cooling process and T_{env} is the environmental temperature. Thereafter, the speed of the cooling for, e.g. a thin person can be calculated with the formula $S_{\mathrm{thin}} = T_{85\%}/19\,\mathrm{h}$. The post-mortem time can then be calculated with the formula $T = (37\,^{\circ}\mathrm{C} - T_{\mathrm{rect}})/S$.

James and Knight's method [1] *is* a practical and much used easy method that takes into account environmental temperature by applying stepwise correction factors for ambient temperature The formula is $T = (37\,^{\circ}\mathrm{C} - T_{\mathrm{rect}}) \times K_{\mathrm{env}}$, where coefficient K_{env} may obtain values of 1, 1.25, 1.5, 1.75 and 2, corresponding to environmental temperatures of 0, +5, +10, +15 and +20 °C. The error limits are ±2 h if the time since death is 10 h or less, and ±3 to 4 h if the post-mortem time is more than 10 h.

Rule of thumb methods [4] are nor recommended for case work, although they are used much in practice to have an estimate of the time of death of patients who died of natural causes. They do not take account any confounding variable. The first formula (I) is as follows: time since death (hours) = $(T_{\mathrm{rect0}} - T_{\mathrm{rec1}})/1.5$, where T_{rec0} is rectal temperature at the time of death and T_{rec1} is the measured post-mortal rectal temperature. Temperature values in the equation are in Fahrenheit degrees but the result is in hours. According to the second formula (II) using Celcius degrees, time of death (hours) = $(T_{\mathrm{rec0}} - T_{\mathrm{rec1}}) + 3$ h.

4. Results

4.1. Homicide case

In this case, the true post-mortem time turned out to be 15.25–15.5 h. Applying the temperature-time of death relating

Table 2
Comparison of different post-mortem temperature measurements methods in estimating the time of death of two bodies found in water environment (hours)

	Homicide case	Accidental drowning case
True post-mortem time (hours)	15.25–15.5	10–12
Henssge		
Without correction factors	16 (12.8–19.2)	24 (19.5–28.5)
With correction factors		
0.35		10.5 (3.5–17.3)
0.7		17.1 (10.1–24.1)
0.9		21.8 (14.8–28.8)
1.1	17.5 (13–22)	
1.2	19 (14.5–23.5)	
James and Knight		
1.25	26.9 (23.4–30.4)	32.8 (19.3–36.3)
Marshall	15.0	17.7
Al Aloussi	19 (13–25)	23 (8–34)
Rule of thumb		
I	25.8	31.5
II	24.5	29.2

Ranges either ±1 S.D. or 95% confidence interval.

Henssge's nomogram with 53 kg body weight, confirmed from the school records and parents, and +5 °C environmental temperature without using corrective factors of body weight gave in average of 16 h (±4.5 h) post-mortem time interval, (Table 2). Using this calculation, the average time of death would be November 14, 19:40 h-about half-an-hour since the girl was last seen, which fit best with the true time of death. Use of recommended corrective factor 1.1 (two thicker wet clothing layers) led to about 17 h 5 min (about 2 h before death) and use of 1.2 (more that two thick wet layers) to in average 19 h (3–4 h before death).

According to the Triple-Exponential Formula (TEF) method, the intercept *R* for 15.5 °C rectal and +5 °C environmental temperature was 0.33. By reading the rectal cooling curve for the covered body at the level of the *R* intercept, the post-mortem time was 19 h (with 1 S.D. 13–25 h). According to the modification of *Marshall* the calculations are $T_{85\%} = 0.85 \times (37 - 5\,^{\circ}\mathrm{C}) = 27.2$; and $S_{\mathrm{thin}} = 27.2/19 = 1.43$ and $T = (37 - 15.5\,^{\circ}\mathrm{C})/1.43 = 15.0$ h. The formula by *James and Knight* gives $T = (37 - 15.5\,^{\circ}\mathrm{C}) \times 1.25 = 26.9$ h ± 3–4 h. The *rule of thumb* methods give $T = (98.6 - 59.9\,^{\circ}\mathrm{F})/1.5 = 25.8$ h or $T = (37 - 15.5\,^{\circ}\mathrm{C}) + 3$ h = 24.5 h.

4.2. Accidental drowning case

Here the post-mortem interval was deduced to be 10–12 h. The application of *Henssge's nomogram* using 53 kg body weight and +4 °C environmental (water) temperature without corrective factors gave as a result 24 h (Table 2) exceeding the known post-mortem time (10–12 h) in mean by 11 h. By applying body weight corrected with the factor 0.35 would give 10.5 + 7 h, whereas 0.7 would give 17.1 ± 7 h. Correction factor 0.9 would give 21.8 ± 7 h.

In the Triple-Exponential Formula (TEF) method, the intercept *R* was 0.21 and the post-mortem time for the drowning case 24 h. (1 S.D. is 18–34 h). According to *Marshall*, the calculations are as follows: $T_{85\%} = 0.85 \times (37 - 4\,^{\circ}\mathrm{C}) = 28.05$, and $S_{\mathrm{thin}} = 28.05/19 = 1.48$ and $T = (37 - 10.8\,^{\circ}\mathrm{C})/1.48 = 17.7$ h. Using the *James and Knight's* formula $T = (37 - 10.8\,^{\circ}\mathrm{C}) \times K_{\mathrm{env}}$, where coefficient K_{env} for +5 °C environment is 1.25, the post-mortem interval would be 32.8 ± 3–4 h. *Rule of thumb methods* gave $T = (98.6 - 51.4\,^{\circ}\mathrm{F})/1.5 = 31.5$ h or $T = (37 - 10.8\,^{\circ}\mathrm{C}) + 3$ h = 29.2 h.

5. Discussion

Although, determination of the time of death is one of the most important and crucial areas in forensic science, there is a surprising lack of reports on the application and validity of different methods in real situations. We evaluated the applicability and accuracy of five methods advocated to be used in practice in two cases found in cold water environment, of which one turned to be a homicide and the other one accidental drowning. We found that Henssge's nomogram method with correction factors was the most versatile and gave the most accurate results in both cases.

Of the other practical methods, that of Marshall's [13] gave also accurate results in the first homicide case, where the correction factor was close to 1.0, thus mimicking standard situation. In the other case Marshall's method was less useful. The triple-exponential formula (TEF) method [9–11] was originally intended to be used without knowledge of the victim's weight or height. Although, the true post-mortem time fitted within the error limits of the TEF method, at present the method can only be applied to naked or covered bodies in standard room temperatures, and it is at its current form unreliable to be used in real complex homicide cases.

Similarly, the application of the other methods, found previously to give reliable results by one temperature measurement in standard conditions [4], would have led to seriously wrong conclusions in both cases, suggesting that their use should be restricted in death time determination in non-criminal cases.

The basic success in the development of modern methods to measure body cooling is based on the finding that the rectal cooling curve during the first 12 h does not obey Newton's Law, but is sigmoid showing three main phases, i.e. lag period, linear phase and quasi-exponential phase. The deviation from Newton's law in the first part is suggested to be due to post-mortem metabolism of glycogen whereas the causes of the late non-linear quasi-exponential phase are not clear. The modelling of rectal cooling mathematically was achieved by Marshall and Hoare [6] and has most probably been one of the most important contributions to the development of forensic medicine. Their formula is based on integration of two exponential terms: one describing the post-mortal plateau of the temperature drop and another one based on Newton's Law of cooling describing the exponential drop of the temperature after the initial plateau [12]. The validity of this mathematical model was confirmed by experimental studies on a dummy model by Henssge [8] and in a series of studies on human cadavers [12].

The basic advantage of the Henssge's model is that it takes into account simultaneously the effect of body size as well as rectal temperature and environmental temperature as continuous variables instead of a stepwise calculations, e.g. for thin, moderately sized or fat bodies. However, in real human cases, the time of death remained in 18% outside the limits of the 95% confidence intervals [12], which should be kept in mind especially in homicide investigations. The most important drawback is the current limited supply of case-derived data to be applied on choosing correction factors [8,13].

The knowledge about the effect of water immersion on body cooling is based on a the study by Henssge and co-worker [12,14], in which on 29 corpses with known time of death were immersed undressed in a tub holding 1,000 l water of temperatures 20, 10 or 0 °C. It was found that the wet naked bodies cooled more rapidly than bodies in standard environment and that the body weight had to be multiplied by a corrective factor of 0.5 to obtain correct post-mortem times. Unexpectedly, the cadavers that were kept in water with a temperature of 0 °C cooled more slowly especially at rectal temperatures down to approximately 11 °C independently of the body mass. As an explanation of this, a decrease in the thermal conductivity of the subcutaneous adipose tissue in connection with a decrease in tissue temperature was suggested.

The effect of wet clothing is problematic. Usually clothing decreases the evaporation and conduction, but the data on the effect of wet clothing is limited. To our known the effect of wet clothing on body cooling has only been studied by Henssge and Brinkmann [14] in association of a court case. In that study, 12 clothed cadavers were immersed for 4–10 min in water and were left overnight with wet clothing in closed room or were laid out on wet lawn. The results were interesting. In closed room environment, naked bodies with suspended in water for a short time (4–10 m) cooled more rapidly compared to non-soaked ‘‘dry’’ cadavers, so that the correction factor was 0.75 of the real body weight. However, even thin wet clothing prevented heat loss, and in cadavers with, e.g. wet pants and three layers of clothes the body weight had to be corrected by a factor of 1.1–1.3. If the air in the room was set in motion, the correction factors of bodies with thin but soaked clothes dropped to 0.7–0.9. Bodies with more layers of wet-through clothing seemed to cool in moving air like non-soaked bodies, in which no corrective factors are needed. In three bodies lying out in still night on wet lawn wet clothes seemed again to prevent heat loss, and body weight had to be multiplied by factors ranging 1.1–1.4 to obtain the true post-mortem time.

Based on the above, we suggested in the homicide case that although wet clothes may decrease heat loss, on the other hand, respectively, lying over night in open air in the cold shallow ditch with a few centimetres of water (at the time of discovery of the body) and mild wind might have increased temperature loss. It thus seemed that the correction factor of choice in this case would not deviate much from 1.0, i.e. the same than without corrective factors- giving 16 h (±4.5 h). In the calculations, however, we assessed that the true corrective factor might range from 0.8 to 1.2. Based on calculations, it seemed that the death of the girl had most probably occurred close to time she was last seen alive. This was among the facts that led police to re-focus their studies on suspects known to be in the area during that time.

In the accidental drowning case, available data on correction factors is even more limited. We could find only one report on measurement of cooling of a (naked) body in flowing (5 miles/h = 2.2 m/s) water [12,15]. That report dates back to almost 30 years and the data was later used by Henssge [12] to calculate the corrective factor which in that case was 0.35. In our case, with known post-mortem time of 10–12.5 h, it can be assessed that, to obtain correct post-mortem time using the nomogram, the naked body weight should be corrected by a factor of 0.3–0.5. Our results thus confirm the calculations above and suggest that correction factors of 0.5 or lower may fit in cases where the victim is found in flowing water wearing wet clothes.

Our second case drowned under the influence of alcohol. It has been suggested that alcohol consumption increases heat loss by causing vasodilatation of skin vessels. Thus, alcohol might be considered as one factor leading to hypothermia prior to death and might cause lower initial temperature value (below 37 °C) and more rapid body cooling. This concept is, however not supported by experimental human data. In a study [16] on the effect of alcohol on thermal balance in cold water 10 subjects rendered hypothermic by immersion for 45 min in 10 °C water, body core cooling rates and changes in skin temperatures were insignificantly different from controls, even if the exercise period was imposed. In another study [17], healthy volunteers were exposed to controlled cold surroundings in a climate chamber after giving them alcohol both intravenously and per orally so that the maximum blood alcohol concentration measured was 57 mmol/l, corresponding to 2.62%. Alcohol infusion caused a rapid elevation of skin temperature. Exposure to cold caused a rapid fall in surface temperature back to pre-alcoholic infusion values, most probably due to vasoconstriction. During cold exposure, core temperature remained unchanged. These studies thus suggest that the effect of alcohol on body cooling in water may be negligible.

The almost only significant differences between the circumstances of our two cases were the presence of alcohol and the flow of water. While the girl was lying in almost still water that had most probably had a small flow during the night due to rainwater accumulating and slowly disappearing from the ditch, in the other case the flow of water effectively increased heat conduction and loss. More experimental studies and case reports are clearly needed. The recommended corrective factors could be checked experimentally using the dummy model by Henssge and the cooling characteristics of the cases. However, these kinds of weather and temperature conditions may be difficult to arrange experimentally. The possibility of combination of all conditions occurring simultaneously in the nature of Finland in November during next years is also low.

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