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A Computer Program for the Estimation of Time of Death

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ABSTRACT: In the 1960s Marshall and Hoare presented a "Standard Cooling Curve" based on their mathematical analyses on the postmortem cooling of bodies. Although fairly accurate under standard conditions, the "curve" or formula is based on the assumption that the ambience temperature is constant and that the temperature at death is known. Also, Marshall and Hoare's formula expresses the temperature as a function of time, and not vice versa, the latter being the problem most often encountered by forensic scientists.

A simple BASIC program that enables solving of Marshall and Hoare's equation for the postmortem cooling of bodies is presented. It is proposed that by having a computer program that solves the equation, giving the length of the cooling period in response to a certain rectal temperature, and which allows easy comparison of multiple solutions, the uncertainties related to ambience temperature and temperature at death can be quantified, substantiating estimations of time of death.

KEYWORDS: forensic science, cooling, BASIC, time of death estimation, postmortem interval, computer

Estimation of the time of death is a task frequently encountered by forensic scientists. It has long been known that the cooling of bodies reflected the duration of the period since death and several attempts have been made to quantify the cooling rate [*1*]. Also, equations that allowed the calculation of the cooling period have been proposed. These equations have relied mostly on the Newtonian exponential thermodynamical formulae, but when held against empirical measurements of temperatures of cooling bodies, clear discrepancies were observed, especially because of a "lag period" or "plateau" with very little cooling in the period immediately after death [*2*]. This in turn led several investigators to amend their equations, for example, by arbitrarily adding 45 minutes to the resultant periods [*3*].

In the 1960s Marshall published a series of papers with a revised cooling equation [*4–8*]. A second exponential term was added to the Newtonian equation, based on empirical observations, and the resulting formula proved quite accurate in predicting the rectal temperature after even 14 hours of cooling. Furthermore, a "Standard Cooling Curve" was proposed using average values.

$$\Theta_r = \left(\left((\Theta_d - \Theta_a) - \frac{Z(\Theta_d - \Theta_a)}{Z - p}\right)e^{-Zt}\right) + \left(\frac{Z(\Theta_d - \Theta_a)}{Z - p}\, e^{-pt}\right) + \Theta_a \qquad (1)$$

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where

Θ_r = rectal temperature
Θ_a = ambience temperature
Θ_d = rectal temperature at death
Z, p = constants
t = length of cooling period

However, the formula was based on two major assumptions: a constant ambient temperature and a known temperature at death. These two assumptions have always been made by investigators dealing with mathematical expressions of body cooling, but have also been the reason for dismissal of cooling equations by other forensic scientists [*9*]. It is held that because cooling formulas have these inherent uncertainties anyway, one might as well use more simplistic rules (for example, 1° of cooling per hour since death, etc.).

Furthermore, the formula developed by Marshall and Hoare has perhaps not gained the wide use it deserves, mainly because of the mathematics involved: the formula (see the equation) expresses the temperature as a function of a given datum in the cooling period, but the opposite is the more required: expressing the cooling period as a function of a certain body temperature. The equation cannot readily be solved in the latter sense due to the double-exponential nature of the equation. Hence, several investigators (including Marshall and coworkers) have tried to simplify the equation [*10,11*] or have resorted to the construction of normograms [*12,13*].

With the advent of microcomputers, the solving of the equation is simple. This has been used by other authors, for example, Hiraiwa et al. [*14*], although mainly involving more complicated thermodynamical models. A computer program that solves the equation by iteration is presented here. Also, the fast solving of the equation makes multiple calculations possible, which enables the user to enter different parameters, and analyze and compare the effects on the cooling period. Thus the previously mentioned uncertainties involved in temperature at death and ambience temperature may be quantified.

The Program

The program is written in BASIC, using Microsoft QuickBasic ver. 4.5 [*15*]. The full program, with a screen picture as in Fig. 1, was compiled resulting in a commandline executable program, which should run on any IBM-compatible computer, equipped with EGA/VGA color graphic adapter.

Firstly, the program calculates Marshall's constant Z, termed the cooling factor [*4–8*], and an average value for the constant p is chosen. Marshall found that the cooling factor Z actually first assumed a constant value after 12 h of cooling, but also that a linear relationship then existed between Z and the so-called "size-factor." The size-factor (total body surface area divided by mass) is further modified according to the surface area available for cooling. Thus, for a naked body, lying in a supine position 80% of the body surface will be available for cooling, in a crouched position only 60% [*5*]. The constant p is related to the cooling factor, but average values following Marshall [*5*], one for naked bodies ($p = 0.4$) and one for clothed bodies ($p = 0.3$), are employed.

The computer program thus takes both clothing and position into account when solving the equation. The total body area is calculated, based on the formulae provided Du Bois [*16*], and the program then asks if the body is clothed or naked and in a supine or "crouched" position (see Fig. 1). According to the entered answers the relevant value of p is used, and Z is calculated using Marshall's linear relationship: Z = [size factor] $\times$ 0.0006125 $-$ 0.05375 [*4*]. In order to apply Marshall's empirically established constants and equations closely, the unit for temperature in the calculations is Fahrenheit, but a few program lines are inserted for conversion to centigrade.

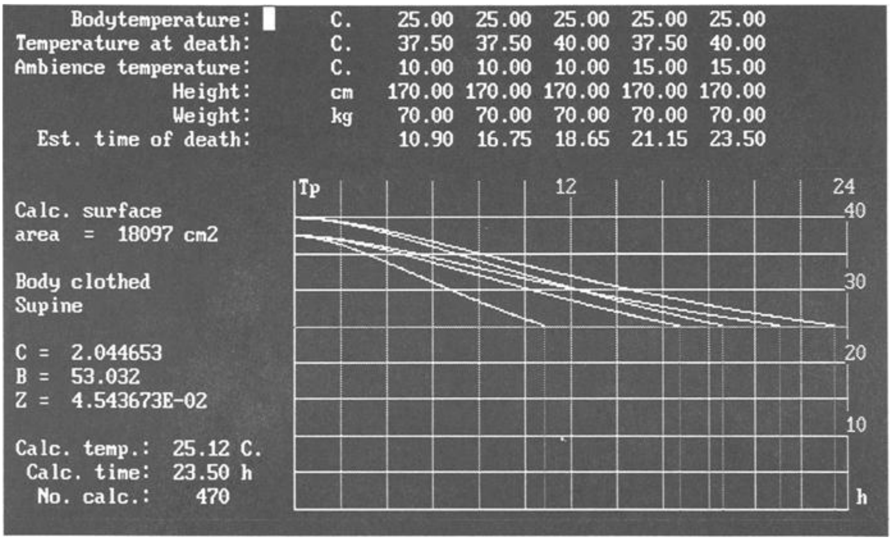

FIG. 1—*Image of computer screen, showing the full program display. The values are input in the upper left box; calculated surface area, clothing and position of body and calculated constants (Marshall and Hoare's C, B and Z) are displayed in middle left box; the interim results (calculated temperature and calculated length of cooling period), along with number of iteration is displayed in lower left box; previously entered values and calculated length of cooling period is displayed in upper right box. The graphical display shows the course of the cooling.*

The program then solves the above equation by iteration, that is, once a temperature at death and an ambient temperature has been assumed, it commences to calculate what the temperature would be after 3 min of cooling. This result is compared to the entered actual rectal temperature. If the calculated temperature exceeds the actual rectal body temperature, the calculation is repeated, adding another 3 min of cooling time, etc., until a temperature is calculated that corresponds, plus or minus 0.25°, to the actual rectal temperature.

The program saves the entered parameters along with the calculated results in the upper right box (see Fig. 1), so that multiple calculations, using different parameters can be made and the results quickly compared.

A graphical representation of the course of the cooling is also given by the program (see Fig. 1). This gives a visual understanding of how changing some of the parameters affect the cooling rate. Upon calculation, the interim results are presented in the lower left box along with number of iterations.

Discussion

The presented computer program is a direct implementation of the cooling formulae presented by Marshall and Hoare in the 1960s. No attempts have been made to "refine" or alter the formula. Since Marshall disposed over a large empirical set of data, it was also felt that no further accuracy would be gained by conducting own observations. The formula was developed by studying the cooling of naked bodies, lying in a supine position, under standard conditions (known constant ambience temperature and known temperature at death). When analyzing Marshall's data the average variation coefficient (percent error) on calculating the time of death for a series of 40 individuals was found to be 13% [*6*]. A series of observations was also carried out for clothed bodies, which led Marshall to calculate some slightly different average values for p (see previous), but this series only included ten individuals (although not presenting data to allow the calculation of error, Marshall states that "Agreement between the observed and calculated temperatures was very close; better than in the experiments on naked bodies" [*5*]. Henssge [*12,13*] made similar observations on a series of clothed individuals ($N = 21$) and largely confirmed Marshall's observations.

Error is also introduced, of course, by using an average value for Z, established based upon an assumed 12 h cooling period and allowing for only two body positions. Marshall did find that, "in general, the average constants give as good an average result as do those obtained by analysis, (whilst) it also shows that in an individual case an increased error might be introduced" [*6*].

There remain, though, the problems of temperature at death and the ambience temperature. Several investigators have tried to circumvent these problems by using multiple measurements [*17*] and simultaneous measurements at different sites [*18*]. The question is though, if the obtained results justify the more complicated methods of assessment.

Instead of trying to eliminate the uncertainties of temperature at death and ambience temperature, it is the aim here to emphasize that fast calculation of the cooling period, assuming different parameters, pertinent to each case, enables the user to evaluate the impact of different temperatures at death and ambience temperatures.

Even though the variation of the temperature at death always must be taken into account, it is worth noting that out of a total of 2000 admissions to the Leeds mortuary, Marshall only found 28 cases (1.4%) with an unexpected high rectal temperature [*6*]. Finally, the ambience temperature may in fact be quite stable: consider the situation of the deceased lying in a room with thermostat regulated room temperatures.

In the example shown in Fig. 1, a series of calculations has been made with several different assumptions. The first column shows the length of the cooling period for a naked body weighing 70 kg and with a stature of 170 cm. The calculated period of cooling from an assumed temperature at death of 37.5°C to the actual rectal temperature of 25°C is 10.9 h. The next column shows the result if the body was clothed; the cooling period then equals 16.75 h. Assuming that the body was clothed, but that the temperature at death may have been elevated (40°C) and that the ambience temperature could be between 10°C and 15°C, the following columns display the impact changing these values has on the length of the cooling period; this varies from 16.75 h assuming the low temperature at death and the low ambience temperature, to 23.50 h assuming the higher temperatures.

Marshall rightly stated that "the timing of death by means of temperature can never be more than an approximation" [*6*]. This does not mean though, that attempts to establish time of death by temperature should be abandoned, or that only simplistic calculations should be carried out. With the existence of empirically accurate equations under standard conditions and computer calculating power, the inherent uncertainties of establishing the time of death mathematically, may rather be assessed and quantified.

Conclusion

A simple computer program that allows fast calculation and graphical representation of the cooling of dead bodies is presented. The algorithms are based on the equations devised by Marshall and Hoare. No attempts have been made to circumvent the problems of ambience temperature and establishing the temperature at death. Rather, the program can run several calculations and present the results to allow comparison, so that different parameters may be assumed, and their effect on the length of the cooling period be assessed.

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References

[*1*] Knight, B. H., "The Evolution of Methods for Estimating the Time of Death from Body Temperature," *Forensic Science International*, 1988, Vol. 36, pp. 47–55.

[*2*] Nokes, L. D. M., Hicks, B., and Knight, B. H., "The Postmortem Temperature Plateau—Fact or Fiction," *Medicine Science and the Law*, 1985, Vol. 25, pp. 263–264.

[*3*] De Saram, G., "Estimation of Death by Medical Criteria," *Journal of Forensic Medicine*, 1957, Vol. 4, p. 47.

[*4*] Marshall, T. K. and Hoare, F. E., "Estimating the Time of Death. The Rectal Cooling After Death and Its Mathematical Expression," *Journal of Forensic Sciences*, 1962, Vol. 7, pp. 56–81.

[*5*] Marshall, T. K., "Estimating the Time of Death. The Use of the Cooling Formula in the Study of Postmortem Body Cooling," *Journal of Forensic Sciences*, 1962, Vol. 7, pp. 189–210.

[*6*] Marshall, T. K., "Estimating the Time of Death. The Use of Body Temperature in Estimating the Time of Death," *Journal of Forensic Sciences*, 1962, Vol. 7, pp. 211–221.

[*7*] Marshall, T. K., "Temperature Methods of Estimating the Time of Death," *Medicine Science and the Law*, 1965, Vol. 5, pp. 224–232.

[*8*] Brown, A. and Marshall, T. K., "Body Temperature As a Means of Estimating the Time of Death," *Forensic Science International*, 1974, Vol. 4, pp. 125–133.

[*9*] Simonsen, J., Voigt, J., and Jeppesen, N., "Determination of the Time of Death by Continuous Postmortem Temperature Measurement," *Medicine Science and the Law*, 1977, Vol. 17, pp. 112–121.

[*10*] Green, M. A. and Wright, J. C., "The Theoretical Aspects of the Time Dependent Z Equation As a Means of Postmortem Interval Estimation Using Body Temperature Data Only," *Forensic Science International*, 1985, Vol. 28, pp. 53–62.

[*11*] Brown, A. and Marshall, T., "Body Temperature As a Means of Estimating the Time of Death," *Forensic Science International*, 1974, Vol. 4, pp. 125–133.

[*12*] Henssge, C., "Die Prazision von Todeszeitchatzungen durch die mathematische Beshriebung der recktalen Leichenabkuhlung," *Zeitschrift für Rechtmedizin*, 1979, Vol. 83, pp. 45–67.

[*13*] Henssge, C., "Todeszeitchatzungen durch die mathematische beshriebung der rektalen Leichenabkuhlung unter verschiedenen Abkuhlungsbedingungen," *Zeitschrift für Rechtsmedizin*, 1981, Vol. 87, pp. 147–178.

[*14*] Hiraiwa, K., Ohno, Y., Kuroda, F., Sebetan, I. M., and Oshida, S., "Estimation of Postmortem Interval from Rectal Temperature by Use of Computer," *Medicine Science and the Law*, 1980, Vol. 20, pp. 115–125.

[*15*] Microsoft QuickBASIC, version 4.5. Microsoft, U.S.A. (1990).

[*16*] DuBois, D. and DuBois, E. F., "A Formula to Estimate the Approximate Surface Area if Height and Weight be Known," *Archives of Internal Medicine*, 1916, Vol. 17, p. 863.

[*17*] Nokes, L. D. M., Brown, A., and Knight, B. H., "A Self-Contained Method for Determining Time Since Death from Temperature Measurements," *Medicine Science and the Law*, 1983, Vol. 23, pp. 166–169.

[*18*] Morgan, C., Nokes, L. D. M., Williams, J. H., and Knight, B. H., "Estimation of the Post Mortem Period by Multiple-Site Temperature Measurements and the Use of a New Algorithm," *Forensic Science International*, 1988, Vol. 39, pp. 89–95.

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