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PAPER

PATHOLOGY/BIOLOGY

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Algor Mortis: An Erroneous Measurement Following Postmortem Refrigeration*

ABSTRACT: Determination of the time of death is one goal of medicolegal death investigations. Algor mortis has been used as a measure of the postmortem interval (PMI). We prospectively recorded the core temperatures of 19 adult bodies entering our morgue cooler and at 3, 6, and 9 h of refrigeration. We then compared the cooling rate with the calculated body mass index (BMI). For each individual body, the rate of cooling was fairly linear with no evidence of a plateau. There was fair to moderate correlation between the BMI and the cooling rate: cooling rate = −0.052 (BMI) + 3.52. The probability of linearity in any given case was 36%. Variables affecting this correlation included the presence and the layers of clothing and if the clothing was wet. Our data confirm that algor mortis is of very limited utility in determining the PMI in bodies that have been refrigerated.

KEYWORDS: forensic science, algor mortis, postmortem interval, time of death, morgue refrigeration

A large body of research has been dedicated to finding a dependable, scientific method to determine the time of death. The postmortem interval (PMI) is sometimes extremely important in cases of homicide whereby the suspect can be convicted or exonerated depending on his or her whereabouts at the time of a crime. In popular television shows, the time of death is portrayed as an exact science; reality suggests otherwise. Algor mortis, the cooling of the body after death, is prominently featured in fictional scenarios. Although it may provide some useful information regarding the PMI in routine forensic casework, it should not be used as the sole determinant of the time of death (1,2).

There have been several classical methods described to determine the PMI by measurement of the core body temperature. Moritz calculated the number of hours which elapsed since death as (3):

$$\frac{98.6^{\circ}\mathrm{F} - \text{rectal temperature degrees F}}{1.5} = \text{PMI in hours}$$

Simpson offered a guideline that states "under average environment conditions, the clothed body will cool in air at rate of two and one-half to 2°/h for the first 6 h and averages a loss of one and one-half to 2°/h for the first 12" (4). In contrast, Shapiro proposed that "apparently healthy persons who died at known times retained normal body temperatures for the first 4–5 h after death, giving rise to a so called postmortem plateau" (3).

Moritz's, Simpson's, and Shapiro's assertions assume a body of average build and a normal ambient temperature at the time of death. As anyone involved in forensic practice is aware, many bodies are not of average build. Further, ambient temperatures are rarely room temperature. Depending on the locale and season, a body may be exposed to a temperature range of −40°F to 120°F. The aforementioned formulas and guidelines do not apply under those conditions.

More recently, Molnar et al. analyzed the fall in rectal temperature in 55 postmortem cases during refrigeration in a mortuary. The study concluded that there was a constant percent cooling rate over the first 24 h followed by a less steep cooling trend. A slower drop in core body temperature was correlated with increased pelvic circumference and diffusivity of fat (5). The best method to date for determining the PMI from body temperature was researched and published by Henssge. Henssge created a nomogram applying Newton's law of cooling approximating a sigmoid-shaped cooling curve. This formula has two exponential terms within it. The first constant describes the postmortem plateau and the second constant expresses the exponential drop of the temperature after the plateau according to Newton's law of cooling. Introducing more than two exponential terms complicates the theoretical model without producing better results in practice. In an individual case, the constant expressing the exponential drop of the temperature after the plateau is simply calculated from the body weight. The first constant that describes the postmortem temperature plateau was found to be significantly related to the second constant in that bodies with a low rate of cooling have higher body weights (6). In short, heavy people are insulated and do not cool as fast as thin people.

We have hypothesized that in a controlled ambient temperature, a morgue refrigerator, and with a known initial body temperature, one should see a linear drop in body temperature rather than a plateau. Further, the rate of cooling for an individual body should decrease as the body mass increases. A formula should be able to be developed expressing this relationship using only one variable, the body mass index (BMI).

Methods

The core body temperature upon admission to the morgue was measured by a percutaneous puncture of the liver on 19 nonconsecutive bodies. We recorded the core temperatures at the 3, 6, and

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9 h postrefrigeration intervals. The gurneys in our study were positioned centrally in the walk-in cooler and subjected to convection equally at a constant temperature of 40°F. The PMI prior to arrival at our facility was variable as were the causes of death. None of the decedents suffered from hypothermia prior to refrigeration. The cadavers' BMI in kg/m^2 was calculated based on their height, body weight, gender, and age classified using standard tables (7): normal weight range = 18.5–24.9; overweight = 25–29.9; obesity = BMI of 30 or greater.

The cooling rate was calculated with respect to the BMI with the bodies grouped into normal-overweight versus obese. Other variables recorded and analyzed included the layers and condition of the clothing, the cause and manner of death, and all relevant prior medical history.

Results

Not unexpectedly, we found that the rate of cooling of a body stored in a refrigerated environment was affected predominantly by cadaveric factors, namely the BMI and the clothing (Table 1). For each individual body, the rate of cooling was fairly linear with no evidence of a plateau. There was fair to moderate correlation between the BMI and the cooling rate: cooling rate = −0.052 (BMI) + 3.52; however, there was only a 36% chance of any given case falling on this curve (Fig. 1). Variables affecting this correlation included the presence or absence of clothing (clothed bodies cooled slower); the layers of clothing present (unclothed bodies cooled faster); and if the clothing was wet (resulting in rapid cooling). As a general rule, the average obese body cooled at a slower rate than a normal to overweight body. Based on Henssge's studies, the cooling rate in a refrigerated environment should be linear. In our study, when the cooling rates for all of the decedent bodies were analyzed, this relationship did not appear to hold. As illustrated in Fig. 2 (black line), the cooling rate appeared to be biphasic with the rate of cooling slowing between 6 and 9 h. We therefore considered possible factors that might be responsible for this effect. One possible factor is obesity as reflected in the BMI. We therefore separated the data from decedents in the normal to overweight range from decedent bodies that were obese based on BMI calculations. What we found was that the Henssge algorithm held for the normal to overweight bodies (Fig. 2, blue line) but that the obese bodies exhibited the same biphasic pattern as seen for the total sample (Fig. 2, tan line). These findings suggest that Henssge algorithm may be more complex that originally postulated and that physical factors inherent in the body habitus may alter the cooling rate.

Discussion

Although this study focused on a relatively small sample size over a limited PMI, some very useful data were generated. Our results indicate that the cooling rate of a body placed in a morgue refrigerator has a fair correlation with its BMI. For example, an unclothed body with a BMI of 37.7 had an initial body temperature of 91°F and at the end of the 9-h time interval, the body temperature was reduced to 78°F (a change of 1.4°/h). This is in contrast to a case with a BMI of 22.3 which also initially had a 91°F body temperature but measured 70°F 9 h later (a drop of 2.3°/h) even though this body was clothed. Although there were some exceptions as a generality, the greater the BMI the slower the heat loss.

Clothing served as an insulator of the body, thereby decreasing the rate of temperature loss by half. One body with a BMI of 23.4 had a 102°F body temperature initially and at the end of 9 h, the body temperature was decreased by 32°F to 70°F. This compares to a person with a BMI of 23.7 who was admitted with a 99°F body temperature which decreased by 14°F to 85°F over the same time interval. Although both bodies share a roughly equal BMI, the first body, received in light clothing, cooled quickly compared with the second body that was placed in the cooler wearing many layers of clothing.

It is well known that water is a better conductor of heat then air. In our study, a body that had been immersed in water prior to intake at our facility doubled the expected cooling rate. In this case, the body with a BMI of 29.9 was admitted to our morgue wrapped

TABLE 1—*Correlation of body mass index (BMI) with rate of postmortem cooling at 40°F morgue temperature.*

Case Number	BMI	Cooling Rate (°F/h)	Admit (°F)	3 h (°F)	6 h (°F)	9 h (°F)	Clothing	Light or Layered*
1	18.2	2.8	90	85	73	65	No	N/A
2	18.6	2.4	95	85	80	73	Yes	Gown
3	19.3	2.3	93	90	85	72	Yes	Gown
4†	19.7	2.6	95	82	77	72	No	N/A
5	22.2	2.4	83	70	65	61	No	N/A
6‡	22.3	2.3	91	88	84	70	Yes	Light
7§	23.2	2.3	92	85	78	71	Yes	Light
8§	23.4	3.6	102	93	82	70	Yes	Gown
9§	23.7	1.6	99	95	91	85	Yes	Layered
10	23.9	1.6	96	90	86	82	Yes	Layered
11	27.8	2	93	86	80	75	Yes	Gown
12†	29.9	2.9	89	80	71	63	Yes/wet	Layered
13	32.7	2.1	90	82	74	71	No	N/A
14	33.9	1.3	89	85	81	77	Yes	Light
15	34.9	2	92	86	78	74	No	N/A
16	35.5	1.4	88	83	79	75	No	N/A
17	35.6	1.7	101	97	92	86	No	N/A
18	36.5	1.7	92	87	79	77	Yes	Light
19‡	37.7	1.4	91	87	82	78	No	N/A

*Light clothing consisted of a shirt ± pants or vice versa and underwear; layered clothing consisted of the above + an outer garment.
†Cases 4 and 12 show how wet or dry clothing can affect the cooling rate of the body.
‡Cases 6 and 19 show that the greater the BMI the slower the heat loss.
§Cases 7, 8, and 9 show that roughly similar BMIs have different rates of body temperature loss due to insulation by layers of clothing.

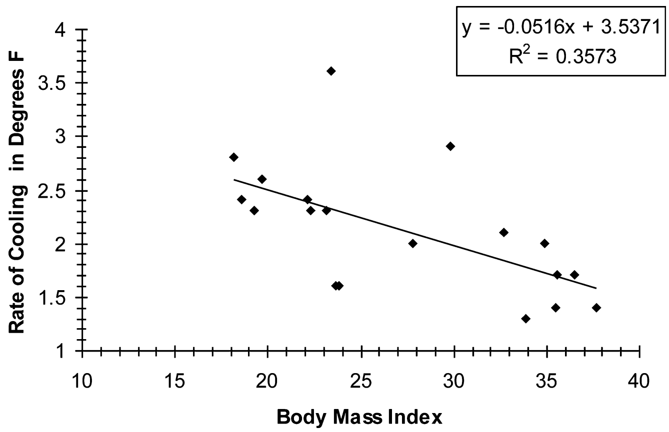

FIG. 1—*Relationship of body mass index (BMI) to average body cooling rate over 9 h. The body cooling rate was slower for those with a higher BMI (obese) and greater for those with a lower BMI (normal to overweight) in this controlled environment (obese = 1.7°/h, all cases = 2.1°/h, normal to overweight = 2.4°/h.)*

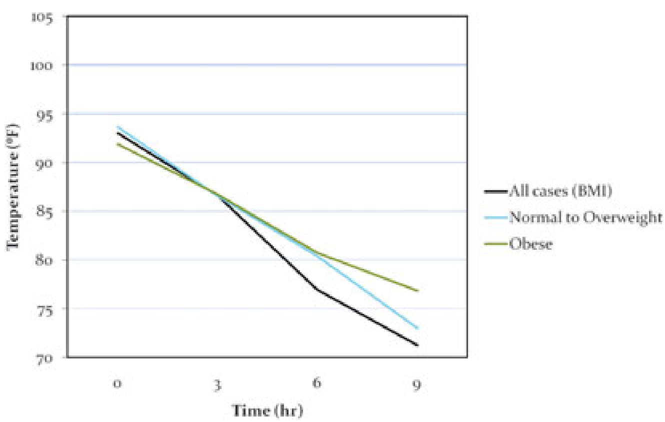

FIG. 2—*Average temperature change over 9 h of refrigeration at 40°F.*

in wet, layered, clothing. Its body temperature dropped by 26°F, from 89°F to 63°F, over 9 h. Comparing this to a body with a much lower BMI of 19.3 received insulated in dry layers of clothing, its body temperature dropped by 19°F from 93°F to 72°F. Although these data are very limited, it would appear to suggest that bodies in wet clothing cool faster than bodies in dry clothing.

The cooling slopes do not support either a rapid linear drop in temperature followed by a plateau or a slow rate of cooling followed by a sharp decrease in core temperature. As noted above, the drop in temperature over time is fairly linear. Using a common formula which has been used to estimate the time of death, PMI = (98.6°F − core temperature)/1.5 and substituting our averaged "admitting" core temperatures and our averaged "9-h" core temperatures, the following calculations can be made: average obese body: (91.9 − 76.9)/1.5 = 10 h PMI; average normal to overweight body: (93.2 − 71.6)/1.5 = 14.4 h PMI; all cases: (92.7 − 73.5)/1.5 = 12.8 h.

Thus, the cooling rate of the average obese body in this study essentially follows this well-known formula (10 h calculated postmortem cooling interval compared with 9 h in actuality). Prolonged exposure to a constant 40°F environment, however, resulted in overestimation of the PMI in normal to overweight bodies.

This study did not attempt to either confirm or refute the rate of cooling of a body postmortem in a nonrefrigerated setting. The cases in this study came to the morgue with an unknown time of death in many cases. Given their temperatures upon arrival to our facility in South Florida (102 − 83°F), it would appear some arrived shortly after death whereas others had been dead many hours prior to discovery. Interestingly, the bodies that were received at a higher initial temperature did not cool any faster than the bodies received at lower temperatures.

Conclusion

The cooling rate of a body placed in a morgue refrigerator moderately correlated with the BMI; however, there was only a 36% probability that any given body will follow a predictable linear cooling curve. Bodies with a low BMI tended to cool somewhat erratically over time, whereas obese bodies cooled at a fairly steady rate that correlated well with results expected from previously published formulas. Although heavier bodies cooled more slowly than leaner bodies as a general rule, many variables affected the cooling rate. Algor mortis, both in this controlled environment and in the real world, is influenced by the presence or absence of clothing, layering of the clothing, and exposure of the body to water resulting in soaked clothing. In summary, the assessment of algor mortis at the time of autopsy as the sole determinant of the PMI is fraught with error. Refrigeration of the body following admission to the morgue essentially renders assessment of algor mortis irrelevant in determining the time of death in individual cases.

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