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Determination of carcass cooling rates using nomograms – a pilot study

Gabriela Vargova, Daniela Takacova, Libusa Bodnarova*

University of Veterinary Medicine and Pharmacy in Kosice, Kosice, Slovak Republic

**Corresponding author: Daniela.Takacova@uvlf.sk*

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Abstract: Knowing the time of death of animals can be helpful for the forensic determination of death due to cruelty. We aimed to determine the time of death of companion animal carcasses, euthanised at an outpatient's department (Small Animal Clinic) of the University of Veterinary Medicine and Pharmacy in Kosice. The reasons for euthanasia included age of animals, medical state or incurable disease which affected the quality of life. Animal carcasses (33 bodies) were divided into seven groups according to their weight, species and environmental conditions into which they were placed, which were chosen so as to imitate real conditions under which dead animals could be found. We continually measured body temperature until it dropped down to ambient temperature. The post-mortem cooling curve revealed dependencies related to the temperature drop, the weight of carcasses, the place where animals rested and the internal and external environment. Results from the cooling process and obtained time of death may be deduced from a nomogram in field practice.

Keywords: nomogram; cooling; temperature; cruelty; animal carcass

The number of techniques employed to determine the time of death has grown in the past twenty years. This is a priority for law enforcement agencies when confirming or excluding alibis of suspects in criminal acts of cruelty to animals. Knowing the time of death (TOD) has assumed increasing importance in cases involving companion animals, wild animals as well as farm livestock. Veterinarians may be involved in a range of incidents including poaching, death of livestock during transportation, cases of neglect or deliberate injury of animals or the actions of irresponsible animal breeders. The dog trade regularly carries out illegal practices, which may involve breaches of transportation and animal welfare legislation and noncompliance, registration and taxes. Determination of the time of death may be crucial in cases where several animals are found and the question arises of whether this was a single episode or an ongoing problem (Munro and Munro 2013).

Various methods are now employed to establish the time of death (Munro and Munro 2013): temperature-based methods, post-mortem chemistry, electrical stimulation of muscles and nerves, gross appearance of the body, rigor mortis, eye shape, colour and luminosity, decomposition, histopathology and electron microscopy, radiology, DNA and RNA analyses, entomology, and environmental and associated evidence.

According to Rogers and Stern (2018), studies on the cooling of animal carcasses suggest that differences exist between the rates of cooling among various species and that the use of human models may not be ideal for application in animal cases. When applying the method of temperature-based estimation to animal carcasses, the investigator should

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pay due attention to the species in question rather than simply extrapolating from data generated from studies of human bodies (Munro and Munro 2013). Current understanding allows an estimation of post-mortem intervals to be classified into broad time periods such as < 24 hours, one to three days, three to seven days, one week, three weeks, one month and one year. Temperature-based methods employ a certain set of rules for determining the time of death in humans: the general rate of cooling is about 0.8–0.6°C heat loss/hour (rectal) at an environmental temperature of 24°C. Cooling is principally a natural process of heat convection, conduction, radiation and evaporation. The mathematical basis of heat conduction is Newton's law of cooling, which predicts an exponential decay in the temperature from its initial to final value, over time (Craig 2010). Post-mortem exchange of heat between the body and a surface takes place only by conduction. Heat is lost from superficial layers first, then from internal parts of the body. The cooling of body parts which are not in contact with the surface takes place by convection. Exchange of heat by radiation, which is important only during the first hours of cooling decreases later and depends on the skin temperature. A small amount of heat lost by evaporation depends on the atmospheric humidity. There are numerous internal and external factors affecting the rate of cooling: the difference in the temperature between the body and the ambient surroundings, the surrounding environment (air, water and the ground), physical condition and disease state (fever, bacteraemia). Pulmonary embolism, infection, septicaemia, thyrotoxicosis, heart attack, poisoning, emotional stress and administration of neurological drugs (stimulants that may cause a body temperature increase) are some of the physiological states associated with increased body temperature. Post-mortem interval estimation has been conducted on human bodies; however, human models of body cooling may not be appropriate for use in animal cases. An ideal model of animal body cooling has not been developed yet. The most commonly used scientific method to determine the extent of body cooling is the measurement of body temperature. As was mentioned, the rate at which the body begins to lose heat to the environment is dependent on many factors. It has been shown that the temperature plateau effect varies significantly and factors such as animal species, cause of death, body region, body size, surface insulation and environmental conditions may affect it (Al-Alousi 2002; Smart and Kaliszan 2012). Three methods for TOD determination have been described. The "rule of thumb" states that the body cools at a rate of 1°C per hour after death, plus a factor of three hours to account for the temperature plateau effect (Shapiro 1965). Perper (2006) and DiMaio and DiMaio (2001) reported a method based on an average rate of body cooling of 0.83–1.11°C for the first 12 hours after death, followed by 0.55°C per hour. Those methods may be adjusted by replacing the 37°C with the expected core temperature for the species in question (Brooks 2016). A nomogram by Henssge and Madea (2004) is the third method used for estimation of TOD in humans. The method requires measurement of the rectal temperature as well as the environmental temperature and estimation of body weight. Precision and repeated accuracy on single rectal measurement remain issues for the nomogram (Al-Alousi et al. 2002) at different ambient temperatures. Rogers and Stern (2018) recommend that at least several of these calculations are considered as each of the formulae will result in different estimated post-mortem interval values. The longer the post-mortem interval, the greater will be the observed difference between formulae. To establish the time of death, we here used formulas derived from Newton's law of cooling which states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature (i.e. the temperature of its surroundings), as well as the rule of thumb (Table 1).

MATERIAL AND METHODS

Animals. Cats and dogs (n = 33) were included in the study (Table 2). Animals were euthanised at the

Table 1. Formulas used for estimating time of death

Rule of thumb = the body cools at a rate of 1°C/h after death
PMI = 37°C – T_{rect} °C + 3
PMI = 98.6°F – T_{rect} °F/1.5 or 37°C – T_{rect} °C/0.83
$t = -10 \ln (T - T_{room}/T_0 - T_{room})$ for internal usage

PMI = post-mortem interval (in hours); t = time of corps cooling; T = temperature; T_0 = physiological temperature by species; T_{rect} = rectal temperature measured in the rectum at the scene; T_{room} = room temperature

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Table 2. Groups of animal carcasses

Group No.	Animal	Body weigt (kg)	n	Ambient temperature (°C)
1	dog	≤ 5	6	18–20
2	cat	≤ 1.9	6	18–20
3	dog	≤ 6.3	2	4–6; outside
4	dog	≤ 5.1	6	18–20; moving air
5	dog	≤ 25	7	18–20
6	cat, dog	≤ 9.04	6	16–8; water, sink
7	dog	≤ 52	1	–3.8; winter outside

Small Animal Clinic at the University of Veterinary Medicine and Pharmacy in Kosice, mainly due to old age leading to reduced quality of life. Pet owners gave written consent for later disposal of carcasses. We carried out euthanasia under the provisions of the Act on Veterinary Care in the Slovak Republic (Act No. 39/2007 Coll. of Laws). We monitored temperature curve in cooling carcasses until full equilibration of body temperature with the environment was achieved. We used a thermometer with two probes (Testo T3 Patent No. 6.66517431 with a measurement range from –50°C to +400°C) to measure the temperature drop in animals immediately after euthanasia. We placed one probe in the rectum at a depth of 5–10 cm according to the size of the animal; a second probe, which is used to measure the ambient temperature, was placed next to the body. The measurement was performed at 30-minute intervals. The animals were divided into seven groups based on species, weight and conditions that could imitate the environment in which dead animals may be found. The first group consisted of small dogs (n = 6) weighing ≤ 5 kg; they were placed at a temperature of 18–20°C. The second group included cats (n = 6) weighing ≤ 1.9 kg under the same conditions as dogs in the first group. Dogs of medium size ≤ 6.3 kg (n = 2) were in group three where external temperature was between 4°C and 6°C. A fourth group consisted of mixed animals weighing ≤ 5.1 kg (n = 6), where animal carcasses were hung above the ground at a height of 1.5 m, in a draught at 18–20°C. Large dogs weighing ≤ 25 kg (n = 7) were in group 5; the temperature of the environment in which they were placed was 18–20°C. Dogs and cats with a weight ≤ 9.04 kg (n = 6) in group 6 were immersed in water at 16–18°C. The seventh group consisted of one large dog weighing ≤ 52 kg; the measured external temperature was –3.8°C. When measuring the temperature (except in groups 4 and 6) animal carcases were in a closed room with windows that had been closed; they were placed on a concrete pad and on an absorbent 5-mm-thick pad. If the temperature was measured outdoors, carcasses (groups 3 and 7) were placed on a wooden pallet; they were secured against undesirable factors (rodents, strangers, etc.) by a pen. The animals of group 4 were placed in the same room (as groups 1 and 2), but the windows and doors had been opened to induce draught. After measuring the body temperature (cooling of the carcass) and the temperature of the external environment, the output was displayed in the form of graphs and tables. To determine the rate at which the carcass cooled down, we used a formula derived from Newton's law of cooling. We found differences when subtracting hours from the temperature curve (the time over which the cadaver cooled down). These differences were probably related to the formula for calculating the time of death that disregarded the plateau phase and temperature fluctuations within the day. We used the measured data to construct a nomogram (Figure 1).

RESULTS

The average rate of heat loss is 1.5°F (0.8°C) per hour under 70–75°F (21–24°C) environmental conditions in humans, and very similar heat loss was reported in dogs (0.6–0.8°C) by Proctor et al. (2009), however, without consideration of all factors influencing the cooling process. Cooling in water is rapid because water is a far better conductor of heat. In our experiment we recorded the fastest cooling in group 2 (2.2°C/h decline). This indicates that the cooling process depends primarily on weight; all bodies in that group cooled in approximately 25 hours. The time required for all bodies to reach the ambient temperature in group 1 ranged from 24 to 26 hours (decline of 2.5°C/h for the first 4 hours). In group 6, the temperature declined by 4°C/h). All carcasses in group 6 were immersed in water with a temperature of 16–18°C. All bodies reached the ambient temperature after 23 hours approximately. In group 4, we exposed animals to natural airflow through open windows and a door and their body temperature declined by 2.8°C per hour, suggesting that airflow gives a two-fold increase in cooling speed. All bodies in group 4 cooled down by 37 hours approximately. Group three (dog carcasses placed outside under

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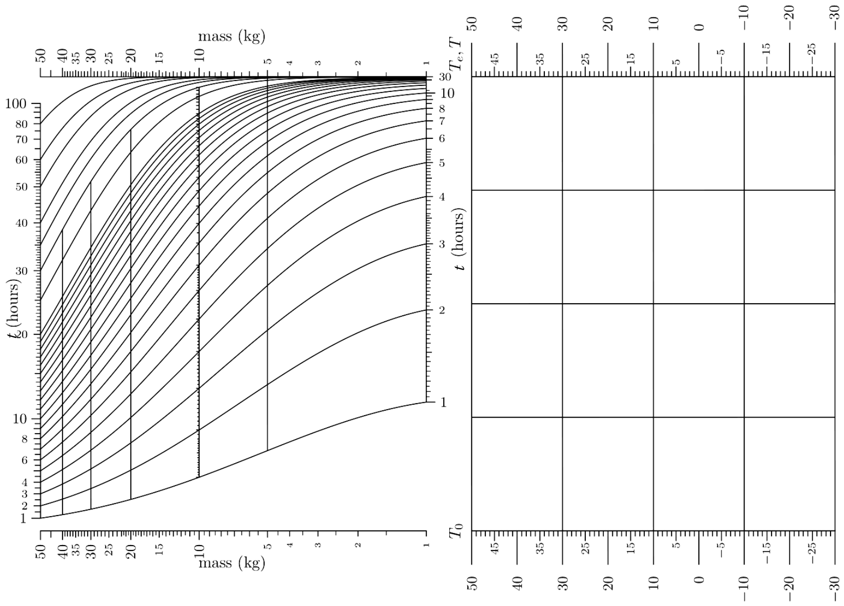

Figure 1. Nomogram for estimating time of death of selected species of companion animals (author: DTech Leif Roschier)
t = time since death (hours); T = rectal temperature measured at crime scene; T_0 = physiological temperature (normothermia) of species; T_e = ambient temperature

winter conditions, with average weight of 15 kg) cooled by 2.4°C/h, and cooling took less than 29 hours. Finally, group 7, comprising a dog over 50 kg and with long fur (Newfoundland breed) was placed outside in January; it initially cooled by only 1.7°C/h due to its mass and good fur isolation, and the body reached ambient temperature after 117 hours (Figure 2, Table 3).

The data obtained allowed the construction of a nomogram (Figure 1). Nomograms can be helpful in explaining when death is likely to have occurred.

During the investigation of a crime scene, when a body is found, pathologists or investigators can measure the temperature of the body, the environment and measure its mass. It is important to document all conditions at the scene such as the presence or absence of wind, water and cover of animals or other insulating covering material. Using these data, a nomogram can be used to determine the most likely time of death. The estimated time since death can be useful for confirming or excluding the validity of a suspect's alibi.

DISCUSSION

Animal cadavers are often found in non-standard conditions. Therefore, determining the time of death by measuring the decrease in body temperature might prove difficult in the field. Estimating the time of death may be difficult at a crime scene owing to natural temperature fluctuations during the day and to the presence of the plateau phase, which can last several tens of hours thus extending the cooling period. After 24 hours, the cooling process can be slowed to a decline of 0.2–0.1°C per hour, and cooling can be significantly extended. More studies are required to establish the use of *algor mortis* rate in the estimation of time of death in dogs and other species in order to standardize the use of patterns and rates of cooling (Abdulazeez and Noordin 2010). Proctor et al. (2009) reported that rectal temperature in dogs was found to decrease by 0.5°C per hour in their study and stated that body density, sex and hair coat density had no effect on cooling rate. In the study of Erlandsson

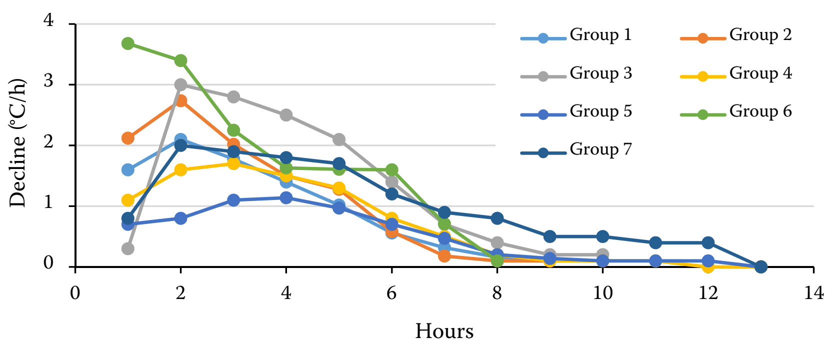

Figure 2. Temperature decline of animal bodies (°C/h)

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Table 3. Comparison of actual hours of cooling (Cool) vs the nomogram method

Group	Dat Eut	W	T_e (°C)	T_0 (°C)	T_i (°C)	Cool	Nom
1	26. 10. 2014	11	19.6	37.1	22.2	18	18
	17. 2. 2015	5	21.7	36.7	22.7	24	17
	22. 12. 2014	3	20.2	36.8	21.4	26	16
	14. 11. 2014	4	19.8	36.1	20.5	25	14
	18. 2. 2014	8	17.9	33.2	19	21	16
	16. 5. 2014	1.2	20.6	34	24.3	cancel	0
2	11. 3. 2016	2.7	18.8	36.5	20.5	63	54
	17. 10. 2014	2	19.1	38.2	20.1	25	10
	2. 6. 2015	0.25	17.6	22.6	17.7	22.5	0
	10. 4. 2015	3.5	18.4	39.6	18.2	14.5	20
	18. 11. 2014	3	19.5	36.9	19.9	23	0
3	21. 1. 2014	11	5.9	37.1	8.2	29	25
4	2. 5. 2016	7	18.7	36.7	19.8	25	17
	17. 5. 2016	7.6	19.1	38.7	19.9	41	25
	10. 6. 2016	9.7	19.1	36.5	19.3	45.5	30
	6. 3. 2015	15	18.7	38.1	21	22	20
	5. 6. 2015	12	19.5	35.8	19.2	21	25
	12. 9. 2016	2.9	22.1	37.1	23.3	27.5	11
	24. 10. 2016	12	20.1	36.1	21.3	53	25
5	3. 3. 2016	38	19	38.1	19.8	70.5	70
	6. 3. 2016	42	19	37.1	21.6	45	42
	24. 10. 2014	15	18.9	38.7	21.3	21	> 30
	30. 10. 2014	43	19.3	41.3	19.3	21	> 30
	27. 6. 2016	23	22.7	37.8	22.8	44	35
	8. 9. 2016	30	24.5	38	24.9	55	> 38
	9. 9. 2016	30	24.5	38.3	21.8	67	> 45
6	14. 10. 2015	6	17.1	27.8	17.3	14	14
	13. 6. 2016	2.8	19.5	36.2	19.6	15	16
	4. 5. 2015	7	21.9	39.2	21.4	20.5	0
	23. 6. 2015	25	19.8	38.9	19.4	45.5	> 40
	8. 4. 2015	4	18.9	36	19.7	22	25
7	31. 12. 2014	56	–3.2	38.6	3.6	> 44	0

cancel = cancelled; Dat Eut = date of euthanasia; Nom = nomogram; T_0 = temperature of the carcass at the beginning of the measurement; T_e = ambient temperature; T_i = temperature of the carcass at the end of the measurement; W = weight

and Munro (2007), it is reported that the rectal temperature of dogs involved in the study reached ambient temperature by 24–48 hours after death with a uniform pattern over the first 10 hours, after which the reliability decreased significantly. The application of methods for TOD determination suggested by Shapiro (1965) and by DiMaio and DiMaio (2001) on the basis of an average cooling rate of 1.5°F (0.83°C) per hour were mentioned also by Merck and Miller (2013). Animal research, however, has shown that the temperature plateau effect is not consistently observed in animal carcasses, and thus the average rate of cooling may differ from that observed in studies of human bodies. To reliably determine the time of death, it is very important to consider additional postmortem changes and entomological findings too. Veterinary pathologists should strongly consider documenting and developing a database of known environmental conditions in their area based on all the necropsies performed, not just those of a forensic nature (Merck 2007). According to Gerdin and McDonough (2013), establishing an accurate and precise TOD remains the holy grail of forensic pathology despite decades of research. In summary, the amount of information available for determining TOD in animals is extremely limited. Given the limited amount of information available along with the inexact science of TOD determination, veterinary pathologists may be guided as much by personal experience as by sophisticated rectal probes (Gerdin and McDonough 2013). In this pilot study, we presented our data for further examination of animal carcasses in different cooling conditions. We found that body weight and initial environmental temperatures are important factors influencing body cooling. These data may assist investigators in narrowing the window of opportunity necessary in order to eliminate specific events and suspects. Proctor et al. (2009) reported that 36% of US households have a dog. The TOD of dogs at a crime scene can be useful in forensic investigations, particularly where human and animal death were concurrent, but also during cases involving the violation and the death of animals. Killing animals is itself a crime. Equally, TOD estimation is also beneficial for livestock depreciation claim investigations. It may be critical to establish the TOD of predatory carnivores, in order to ensure that a livestock manager legally killed it at time when the prey livestock were in the same area (Gonder 2008).

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