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Estimation of time since death using a body cooling model of pigs: A pilot study

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Abstract

Aim : The aim of this study was to test the effects of Korean floor-heating system on heat loss using adult pig models, and to create a novel formula for estimating time since death during the early stages of decomposition.

Methodology : Three electric mattress pads were placed on the ground to maintain a constant temperature of the substrate like the ondol heating system. Four temperature measuring probes were placed in each pig: inside the rectum, on the body surface, between the body and the surface of mattress pad and on the mattress pad. The probes were connected to a temperature data logger system. Temperature was recorded every minute and statistical analysis was performed using the SAS (version 9.3) program.

Results : Spearman's Rank Correlation results demonstrated the rectal temperature, and the temperature between the body and the surface of pad were strongly correlated with postmortem cooling of the body, rather than ambient temperature. The rate of cooling of the body is represented by a cube function of time rather than an exponential or bi-exponential function.

Interpretation : This research indicates that postmortem cooling of the body is more influenced by ground surface temperature than by ambient (environment) temperature, and the rectal temperature fluctuated with the ambient temperature. Additionally, the study showed that pigs can be good animal models that can substitute human cadaver to study the process of decomposition.

Key words: Animal model, Body cooling, Pig, Postmortem interval

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Introduction

In forensic studies it is very important to determine the time since death at early stages of decomposition in daily casework. Algor mortis is the term used for the change in body temperature at early stage of decomposition, until the body temperature has reached the ambient (environment) temperature. Earlier, the most accurate way to measure body temperature was rectal temperature. Henssge reported that rectal temperature was cooled as dependence of the ambient temperature using two exponential equations of Marshall and Hoare (Henssge, 1988; Marshall and Hoare, 1962). Algor mortis can be used to determine the time since death, based on this study.

Henssge nomogram was established by the correlation between postmortem cooling of the body, rectal temperature, ground temperature, and ambient temperature, which is essential for estimating time since death at early stages of decomposition (Henssge, 1988; Henssge, 1992; Althaus and Henssge, 1999; Henssge *et al.*, 2000 a, b; Henssge and Madea, 2004; Henssge and Madea, 2007). The Korean Police Investigation Academy (KPIA) recommends that crime scene investigators employ the Henssge nomogram method at death scene, which is estimated at time since death using rectal and ambient temperature. However, the application of Henssge nomogram is problematic because bodies are commonly found indoors in Korea. Moreover, there is a paucity of research on the effects of heat radiation and Henssge nomogram. In view of the above, the present study was conducted to test the effects of Korean floor-heating system on heat loss using adult pig models, and to create a novel formula for estimating time since death during early stages of decomposition.

Materials and Methods

Four 40 kg pigs (*Sus scrofa*) were killed by administering euthanasia drug for animals, following Soonchunhyang University Institutional Animal Care and Use Committee protocol. Three electric mattress pads were placed on the ground to maintain a constant temperature of the substrate like the ondol heating system. Each pig was placed on four different surfaces; low-heat, medium-heat and high-heat electric mattress pads and ground (that served as control). Four temperature measuring probes were placed in each pig (Fig 1): inside the rectum, on the body surface, between the body and the surface of mattress pad or ground (control), and on the mattress pad or ground (control). The probes were connected to a temperature data logger system and Watchdog 2000 mini-station was located at the research site to measure the ambient temperature. Temperature was recorded every minute and pigs were monitored hourly for 72 hrs by CCTV. Statistical analysis was performed using SAS (version 9.3) program.

Results and Discussion

The data of four temperature measuring probes are summarized in Fig 2. If the rectal temperature was only

influenced by ambient temperature, then the rectal temperature cooling curve should be similar regardless of where the bodies were laid. However, the rectal temperature cooling curve were not same. The rectal temperature of control which was laid on the ground cooled faster than that of experimental group which was laid on the electric mattress. Once the rectal temperature reached that of the ambient temperature, the rectal temperature fluctuated thereafter. As the ambient temperature rose, the rectal temperature rose 2 to 3 hours later, and when the ambient temperature fell, the rectal temperature fell 2 to 4 hours later (Fig 3).

The results of Spearman's Rank Correlation are listed in Table 1. The correlation values between the rectal temperature (T1) and with the temperature between the body and the surface of pad or ground (T2) were 0.998 (control), 0.999 (low-heat), 0.981 (mid-heat), 0.979 (high-heat) ($p < 0.0001$). However, the correlation values between the rectal temperature (T1) and the

Fig. 1: Photographs of the field set-up for estimating time since death using pigs models. (A) Photograph showing an example of control group. A pig was laid down on the ground. In the upper left quadrant, Watchdog 2000 mini station (arrow) was located at the research site to measure the ambient temperature. (B) Photograph showing an example of experimental group. A pig was laid down on the electric mattress. Three pigswere placed on three different conditions; low-heat, medium-heat and high-heat. Four temperature measuring probes were placed in each pig and connected to a temperature data logger system. ① -inside the rectum, ②-between the body and the surface of mattress pad, ③-on the body surface, and ④-on the mattress pad.

ambient temperature (T5) were -0.078 (control), -0.080 (low-heat), -0.084 (mid-heat), -0.086 (high-heat). Therefore, rectal temperature was strongly correlated with the temperature between the body and the surface of pad or ground, rather than the ambient temperature.

The rate of cooling of the body is represented by a cubic function of time rather than an exponential or bi-exponential function (Fig 4; Table 2.). The results of this pilot study were summarized into three aspects comparing the previous studies (Henssge, 1988; Henssge, 1992; Althaus and Henssge, 1999; Henssge *et al.*, 2000 a, b; Henssge and Madea, 2004; Henssge and Madea, 2007). The main result of this study is that postmortem cooling of rectal temperature is strongly correlated with the temperature between the body and the surface where the body was laid. It indicates that postmortem cooling of the body is more influenced by ground surface temperature (radiation heat from the surface) than by ambient temperature.

Ondol is a traditional floor-heating system in Korea, where the floor is heated from below and the heat radiates to warm the room. Bodies are commonly found indoors in Korea, and the application of Henssge nomogram is problematic due to the effects of ondol heating system on the rate of postmortem heat loss in the body. Investigator need to employ another method instead of Henssge nomogram method at death scene during the early stages of decomposition (Megyesi *et al.*, 2005). Meanwhile, rectal temperature measurement maneuver requires a meticulous placement of thermometer, so it is very hard to measure correctly. However, it is relatively easy to measure the temperature between the body and the surface for non-skilled personnel. Secondly, once the rectal temperature reached the ambient temperature, the rectal temperature can be fluctuated by the ambient temperature. Earlier, studies were (Henssge, 1988;

Table 1 : Results of the Spearman coefficient of correlation using the SAS (version 9.3) program

Coefficient of Correlation (SPEARMAN)		Control	Temp 20°C	Temp 25°C	Temp 30°C
Time	T1	-1.000	-1.000	-0.999	-0.997
	T2	-1.000	-1.000	-0.999	-0.993
	T3	-0.870	-0.879	-0.882	-0.856
	T4	0.072	0.345	0.189	0.258
	T5	0.078	0.080	0.082	0.084
T1	T2	1.000	1.000	0.998	0.991
	T3	0.870	0.878	0.880	0.852
	T4	-0.072	-0.345	-0.189	-0.261
	T5	-0.078	-0.080	-0.084	-0.086
	T1	1.000	1.000	0.998	0.991
T2	T3	0.870	0.878	0.880	0.848
	T4	-0.072	-0.345	-0.190	-0.273
	T5	-0.078	-0.080	-0.085	-0.098
	T1	0.870	0.878	0.880	0.852
	T2	0.870	0.878	0.880	0.848
T3	T4	0.318	NS	0.093	0.083
	T5	0.285	0.262	0.240	0.296
	T1	-0.072	-0.345	-0.189	-0.261
T4	T2	-0.072	-0.345	-0.190	-0.273
	T3	0.318	NS	0.093	0.083
	T5	0.963	0.922	0.919	0.924

T1: temperature inside the rectum, T2: temperature between the body and the surface of pad or ground, T3: temperature of the body surface, T4: temperature of the surface of ground, T5: ambient temperature

Henssge, 1992; Althaus and Henssge, 1999; Henssge *et al.*, 2000 a, b; Henssge and Madea, 2004; Henssge and Madea, 2007) carried out with dummy. So once the temperature of dummy

Table 2: Results of the statistical analysis using the SAS (version 9.3) program

		T1*T2		T1*T5		T1*T2*T5	
		Adjusted R-Square	RMSE	Adjusted R-Square	RMSE	Adjusted R-Square	RMSE
Control	Linear Model	0.888	216.763	0.783	301.427	0.894	211.127
	Quadratic Model	0.942	156.400	0.942	155.434	0.996	42.089
	Cubic Model	0.997	37.070	0.986	75.805	0.999	14.849
Temp 20°C	Linear Model	0.913	190.754	0.799	209.005	0.966	120.033
	Quadratic Model	0.973	106.657	0.955	137.020	0.995	44.561
	Cubic Model	0.996	41.139	0.991	961.226	0.998	25.932
Temp 25°C	Linear Model	0.933	167.732	0.780	303.891	0.961	127.142
	Quadratic Model	0.978	95.892	0.926	175.709	0.992	57.649
	Cubic Model	0.996	42.867	0.942	155.54	0.996	40.471
Temp 30°C	Linear Model	0.894	210.684	0.743	327.861	0.923	180.113
	Quadratic Model	0.953	139.667	0.898	206.756	0.984	83.075
	Cubic Model	0.986	77.385	0.962	126.495	0.996	39.606

Adjusted R-square showed large value in cubic model, and RMSE (root mean square error) showed small value in cubic model. The rate of cooling of the body is represented by a cubic function of time rather than an exponential or bi-exponential function. T1: temperature inside the rectum, T2: temperature between the body and the surface of pad or ground, T5: ambient temperature

Fig. 2: Results of cooling curve analysis using rectal temperature. Four cooling curves were identified. If the rectal temperature was only influenced by ambient temperature, then one cooling curve were identified. However, the rectal temperature of control group which was laid on the ground cooled faster than that of experimental group which was laid on the electric mattress. Black- control; Red- low-heat; Blue- medium-heat; and Green- high-heat.

Fig. 3 : Results of cooling curve analysis for ambient temperature and rectal temperature. Rectal temperature (dashed arrow with ②) began to fall when the experiment began. Once the rectal temperature reached (circle with *) that of the ambient temperature (arrow with ①), the rectal temperature fluctuated thereafter. As the ambient temperature rose, the rectal temperature rose 2 to 3 hours after, and when the ambient temperature fell, the rectal temperature fell 2 to 4 hours after.

reached the ambient temperature, it used to be hard to increase the temperature of dummy. So there was no mention after the temperature reached the ambient temperature in the previous study. Also, this study showed that pigs can be good animal models that can substitute human cadaver to study the process of

decomposition. Lastly, the rate of cooling of the body is represented by a cubic function of time rather than an exponential or bi-exponential function (Henssge, 1988). It would be helpful to create a novel formula for estimating time since death during the early stages of decomposition.

Fig. 4: Results of cooling curve analysis comparing quadratic or power function. The rate of cooling of the body is represented by a cubic function of time rather than an exponential or bi-exponential function.

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