Int J Legal Med (2000) 113 : 303–319

ORIGINAL ARTICLE

C. Henssge · L. Althaus · J. Bolt · A. Freislederer
H.-T. Haffner · C. A. Henssge · B. Hoppe
V. Schneider

Experiences with a compound method for estimating the time since death.

I. Rectal temperature nomogram for time since death

Received: 18 November 1998 / Received in revised form: 25 June 1999

Abstract The temperature-based nomogram method for estimation of the time period since death was used at the scene of death as the primary method within a compound method in 72 consecutive cases. The situation and cooling conditions inspected and evaluated by the forensic pathologist at the scene are described as far as necessary to enable handling of the method. A comparison of the estimated period since death with the period determined by the police investigations demonstrates the reliability of the method. There were no contradictions in any of the 60 cases between the period of death estimated by this method and that determined by the police investigations. The criminal investigations were effectively supported in the earliest stages in 11 cases despite the fact that the period estimated was of considerable duration.

Key words Time since death · Nomogram method · Rectal temperature · Practical casework

Introduction

Inspection of the scene of crime by the forensic pathologist who also performs the autopsy is of paramount importance both to him and to the criminal investigators. A medico-legal evaluation of the time interval since death given at an early stage may considerably assist the investigative efforts. Therefore, the reliability of such an evaluation is most essential. Bearing in mind the inter-individual variability of all post-mortem changes which renders the application of individual methods in isolation inefficient, a rational procedure has been designed to integrate a variety of methods (compound method) and which can be applied at the scene [1, 2, 3, 4]. For this purpose, an interactive computer (note-book) program was developed (Henssge CA, http:// home.t-online.de/home/Christoph.Henssge/t-zeit.htm). The examination at the scene takes about 10–15 min and the preliminary estimate is then given. In coordination with the investigators we have used this compound method in casework at the scene. By means of a detailed description and analysis of all cases further experimental experience has been gained and problematic aspects elaborated. All examiners were experienced in using the compound method.

In this article, the main component of the compound method, the temperature-based nomogram method [1, 3, 4, 5, 6, 7] is evaluated. Part II of this study presents the results of the non-temperature-based methods in detail, the procedure, and the integrated results of the compound method.

C. Henssge (✉) · L. Althaus · J. Bolt · A. Freislederer
C. A. Henssge · B. Hoppe · V. Schneider
Institute of Legal Medicine, University of Essen,
Hufelandstrasse 55, 45122 Essen, Germany

H.-T. Haffner
Institute of Legal Medicine and Traffic Medicine,
University of Heidelberg,
Voßstrasse 2, 69020 Heidelberg, Germany

Material and methods

In 72 consecutive cases investigated between November 1993 and October 1997 (Table 1), the scene of crime was inspected by a forensic pathologist and the body was examined in the actual situation as far as possible. Autopsies were carried out in all cases and histological and toxicological examinations were performed if necessary.

Methods and procedure

The examination of the body at the scene began by using the rectal temperature-based nomogram method [1, 4]. The body weight was estimated at the scene to within 10 kg and then measured exactly at the time of autopsy. If necessary, the preliminary estimate of the period since death given at the scene was corrected immediately according to the exact body weights listed in Tables 4–10 and a comment was made if it did not fall within the range estimated.

Cooling conditions which differed from the chosen standard [1, 4, 8] were taken into account by a correction factor (*cf*) of the actual body weight according to Table 2 under three aspects:

a. Clothing/covering of the lower trunk, dry or wet
b. Calm or moving air
c. Type of substrate (increase or decrease of the cooling rate when compared to neutral)

Table 1 Details of the cases evaluated in this study

Case	Sex	Age	Cause of death	Event	Comments
1	m	31	Bleeding, stab wound to heart	Suicide	
2	m	21	Cardiac tamponade, bleeding, stab wound to heart	Homicide	
3	f	78	Bleeding, aspiration of blood, multiple blunt injuries	Homicide	
4	f	25	Manual strangulation	Homicide	
5	f	31	Manual strangulation	Homicide	
6	f	81	Manual strangulation	Homicide	Same scene as 7
7	m	84	Hanging	Suicide	Same scene as 6
8	m	55	Protracted bleeding and finally pneumothorax, blunt force injuries (twice)	Homicide	Survival interval?
9	f	33	Laceration pons and medulla oblongata, bullet wound	Homicide	
10	m	46	Cerebral laceration, bullet wounds	Homicide	
11	m	31	Bleeding, aspiration of blood, stab wound to neck	Homicide	
12	m	49	Bleeding, stab wounds to neck	Homicide	
13	m	48	Skull fractures, cerebral laceration, multiple blunt injuries, and bleeding, multiple stab wounds to heart and lungs	Homicide	
14	f	60	Bleeding, ruptured oesophageal varices	Natural	
15	m	25	Bleeding, bullet wound to lungs and liver	Homicide	
16	m	62	Laceration brain, bullet wound	Suicide	
17	f	27	Strangulation by ligature	Homicide	Stab wound to lungs post-mortem
18	m	42	Aspiration of gastric contents, blood alcohol 3.48‰ urine 4.85‰, multiple blunt injuries to head, neck and abdomen	Homicide	
19	m	28	Hanging (ground contact)	Suicide	
20	f	44	Bleeding, knife wounds to wrists	Suicide	Survival interval?
21	m	44	Strangulation by ligature	Homicide	Survival interval objectified
22	m	37	Bleeding, bullet wound to aorta	Homicide	
23	f	95	Myocardial infarction	Natural	
24	m	37	Strangulation by ligature	Homicide	
25	f	21	Bleeding, multiple stab wounds to lungs, aorta, liver and spleen	Homicide	
26	m	26	Bleeding, multiple bullet wounds to lungs, aorta, carotids and liver	Homicide	
27	f	26	Strangulation by ligature	Homicide	
28	m	54	Bleeding, stab wound to heart	Homicide	
29	m	32	Bullet wounds to brain, spinal cord and lung	Homicide	
30	m	48	Unclear (autopsy, toxicology, histology)	Unclear illness	
31	f	42	80% Surface burns of 2nd–3rd degree	Suicide	Spray-container of inflammable accelerant by the body
32	f	48	Manual strangulation	Homicide	
33	m	25	Amitriptyline/nortryptiline poisoning (2 mg/l, varnish sniffer, no evidence of solvent in lungs)	Suicide/ accident	Malignant hyperthermia?
34	m	53	Bleeding, stab wounds to subclavian artery and vein and lungs	Homicide	
35	m	83	Air embolism and bleeding, combined with cut throat	Suicide	A working storage-ECG was found on the body
36	f	23	Bleeding, aspiration of blood, stab wounds to lungs and neck	Homicide	Same scene as 37
37	m	3	Bleeding, stab wounds to carotid	Homicide	Same scene as 36
38	m	53	Inhalation of fumes (CO and cyanide), 20% surface burns (postmortem?) of 1st–2nd degree	Suicide/ accident	
39	f	50	Combined, internal bleeding (blunt injury), aspiration of gastric contents, alcoholic poisoning	"Accident"	
40	m	38	Bleeding, stab wounds to tibial vein and artery	Homicide	Survival interval?

Table 1 (continued)

Case	Sex	Age	Cause of death	Event	Comments
41	f	42	Hanging	Suicide	
42	m	57	Bleeding, multiple blunt force injuries, multiple sharp lacerations to scalp	Homicide	
43	f	50	Bleeding, stab wounds to lungs in combination with manual strangulation	Homicide	
44	f	74	Strangulation by ligature	Homicide	
45	m	13	Asphyxia and congestion by “headstand” position	Accident (questionable)	Survival interval?
46	f	28	Cerebral laceration, missile retained in skull	Homicide	Same scene as 47
47	m	31	Cerebral laceration, missile retained in skull	Suicide	Same scene as 46
48	m	29	Cerebral laceration, blunt force injuries to head with axe	Homicide	
49	f	22	Bleeding, multiple stab wounds to neck (carotid) and lungs	Homicide	
50	f	54	Bleeding, rupture of liver by blunt injury	Homicide	
51	m	38	Cerebral laceration, bullet wound	Suicide	
52	m	34	Bleeding, stab wound to heart	Suicide	
53	m	35	Bleeding, stab wound to aorta	Homicide	
54	m	34	Morphine (blood, 0.2 μg/ml), alcohol poisoning (blood 1.62‰, urine 3.32‰)	Accident	
55	m	57	Bleeding, laceration of lungs, run over by car	Traffic accident absconding from the scene	
56	m	23	Bleeding, stab wound to heart	Suicide	
57	f	53	Plastic bag suffocation, intoxication, blood, aspirin (200 mg/l), paracetamol (120 mg/l), alcohol (1.79‰)	Suicide	Survival interval?
58	m	38	Bleeding, stab wound to heart	Homicide	
59	f	29	Gastrointestinal bleeding	Illness	
60	f	43	Strangulation by ligature	Homicide	
61	f	40	Bronchial asthma	Illness	
62	f	36	Cerebral laceration and bleeding, blunt injuries to head, stab wounds to neck	Homicide	
63	m	40	Intoxication, chloralhydrate (blood 200 mg/l)	Accident	
64	m	48	Cerebral laceration, bullet wound to brain	Homicide	
65	m	30	Cerebral laceration, blunt force injuries to head	?	
66	m	42	Plastic bag suffocation, intoxication, vinylbarbital 50 mg/l blood	Suicide	Survival period?
66a	f	9	Intoxication, vinylbarbital 10 mg/l blood	Homicide	
66b	m	5	Intoxication, vinylbarbital 25 mg/l blood	Homicide	
67	f	32	Manual strangulation	Homicide	
68	m		Internal bleeding, gastric ulcer with erosion of large vessel	Illness	
69	m	60	Aspiration of blood and bleeding, stab wound to neck	Homicide	
70	m	45	Cerebral laceration, bullet wound to brain, medulla oblongata	Suicide	Same scene as 71
71	f	43	Laceration of cranial region of spinal cord, bullet wound to neck	Homicide	Same scene as 70
72	m	52	Bleeding, stab wounds to subclavian vessels and lungs	Homicide	

By means of the values given in Table 2 a combined *cf* was initially chosen according to the points *a* and *b*. If the substrate was considered to have an influence, the *cf* was increased (>A< or >Ap<) or decreased (>B< or >C<) accordingly, as compared to a neutral substrate. The marks (>figure< and >letter<) were added in Table 2 to support a comparison between the cooling conditions described in Tables 4–10 and the *cf* chosen for each case. As it is impossible to select an exact *cf*, a range was chosen.

In cases with strong insulating conditions and high or low body weight, the chosen range for the *cf* was additionally adapted accordingly [3, 4] by means of the computer program.

The resulting time of death was either read on the nomogram [1] or calculated by the computer program.

The period of death was calculated in two ways:

Table 2 Empirical correction factors (*cf*) of the body weight [1]. The *cf* values listed apply to bodies of average weight (reference 70 kg), in an extended position on a thermally neutral substrate. Only the clothing/covering of the lower trunk is relevant! Marks in >..< were added to support a comparison between the cooling conditions described in Tables 4, 5, 6, 7, 8, 9, 10 and the *cf* chosen for each case. Thermally neutral substrates are normal floors of rooms, dry soil, lawn, asphalt. In comparison, substrates which look more thermally insulating or heat-conducting should be additionally taken into account: see Table 3.10 in [4]:

– >A< Excessively thickly upholstered substrates require a *cf* of 1.3. for naked bodies. In cases of clothed bodies the *cf* should be increased by 0.1 units (thickly clothed) to 0.3 units (very thinly clothed)
– >Ap< Means 'A partially': Insulating but not excessively thickly upholstered substrates such as mattress (bed) or thick carpet require a *cf* of 1.1 to 1.2 for naked bodies. In cases of clothed bodies the *cf* should be increased by 0.1 unit
– >B< Substrates which accelerate cooling, e.g. concrete, stony or tiled substrates on ground require a *cf* up to 0.75 for naked bodies
– >C< In cases of clothed bodies lying on substrates according to >B<, the *cf* should be reduced by 0.1 units for thicker clothes or by 0.2 units for very thin clothes

Dry clothing/covering	Air	Correction factor			Wet through clothing/ covering wet body surface	In air	In water
			0.35	>11<	Naked		Flowing
			0.5	>12<	Naked		Still
			0.7	>13<	Naked	Moving	
			0.7	>14<	1-2 Thin layers	Moving	
Naked	Moving	>1<	0.75				
1–2 Thin layers	Moving	>2<	0.9	>15<	2 Or more thicker	Moving	
Naked	Still	>3<	1.0				
1–2 Thin layers	Still	>4<	1.1	>16<	2 Thicker layers	Still	
2–3 Thin layers		>5<	1.2	>17<	More than 2 thicker layers	Still	
1–2 Thicker layers	Moving or still without influence		1.2				
3–4 Thin layers		>6<	1.3				
More thin/thicker layers		>7<	1.4				
Thick blanket+		>8<	1.8				
Clothing combined		>9<	2.4				
		>10<	2.8				

Table 3 Permissible variation of 95% of the calculated time since death in dependence on the progress of cooling 'Q' according to [1] (Q is defined as rectal–ambient temperature/37.2 °C–ambient temperature)

Progress of cooling	Standard conditions $cf = 1$	Using corrective factor $cf \neq 1$
1.0 > Q > 0.5	±2.8 h	±2.8 h
0.5 > Q > 0.3	±3.2 h	±4.5 h
0.3 > Q > 0.2	±4.5 h	±7.0 h
0.2 > Q > 0.1	Reliability does not exist (–10 h as minimum death time)	

a. The time of death was read off or computed using the mean values for the selected ranges of body weight, correction factor and ambient temperature. The known permissible variation of 95% [7] related to the progress of cooling (Table 3) was added.
b. If the selected ranges of ambient temperature and correction factor were broad, two values for time were read off on the nomogram [1] or computed. The (shortest) time resulting from the combined lower limits of the evaluated ranges of body weight, ambient temperature and correction factor and the (longest) time resulting from the upper limits of body weight, ambient temperature and correction factor were used. The permissible variation of 95% was not added to these values.

If mode *b* of calculation resulted in a broader range of the period since death than mode *a*, this was used and is listed in Tables 4–10. All mathematical calculations were performed automatically by the computer program at the scene by means of a note-book computer.

Results

The data for all 72 cases are described in detail and divided into typical groups to provide practical guidelines for evaluation of both the correction factor and the mean ambient temperature in relation to the findings at the scene (Tables 4, 5, 6, 7, 8, 9, 10)

In some cases in Table 5 (moving air), the situation at the scene indicated that air movement was only temporary and a reduction of the *cf* was chosen between moving and calm air. In case 11 with three layers of clothing, it was debatable whether moving air required a reduction of the *cf* or not but a reduction by 0.1 units was chosen. It should be noted that asphalt (cases 2 and 55) and lawn (case 64) were classified as thermally neutral substrates.

In several cases given in Table 6 combined factors such as moving air, wetness and substrates which appeared to accelerate body cooling were taken into account by using a reduced *cf*.

In the cases of Table 7 the *cf* was increased by 0.05 to 0.2 units depending on the subjective impression of the investigator concerning the insulating features of the substrate.

The bodies of four cases (Table 8) were covered with a blanket; one further case (case 33) covered with a thick blanket is listed in Table 10. The *cf* was chosen by also taking the type of substrate into account. For the body of the 3-year-old boy found lying on the floor on a thick car-

Table 4 Data from cases with no particularity concerning evaluation of both correction factor and mean ambient temperature (*LB* lying on the back, *LP* lying in prone position)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
7	Room, hanging from door, short panty >3</>4<	1.05 (1.0–1.1)	78	20.6/20.6	19.6/21.6	35.0	03.0	08.6	01.8	15.0	Same scene as 6 (Table 8)
12	LB in the pulled out drawer of a bed couch, open trousers >3</>4<	1.05 (1.0–1.1)	50	14.5/17.0	14.5/17.0	31.2	04.1	09.7	07.3	07.8	
14	Room, floor, LB, short panty >3</>4<	1.05 (1.0–1.1)	55	24.0/24.0	22.0*/24.0	31.1	07.8	13.4	05.3	13.3	*Supposedly at night before examining the body in the morning
16	Room, floor, LB, jeans, short panty >4<	1.1 (1.0–1.2)	92	25.2/25.2	23.0*/25.2	28.9	21.3	32.6	29.0	33.0	*Supposedly at night before examining the body in the afternoon
23	Room, floor, LB, skirt, drawers, panties, corselet >6<	1.3* (1.2–1.4*)	45	16.3/17.2	16.3/17.2	30.1	06.1	11.7	09.3	09.4	*The examiner used 1.0–1.3 (mean 1.15) at the scene, inadequately low for 4 layers of clothing resulting in a somewhat shorter interval, 5.1–10.7 hpm
24	Room of a caravan, sitting position on a bench, jeans, short panty >4<	1.1 (1.0–1.2)	62	08.4/09.1	08.4/09.1	31.5	03.7	09.3	05.8	08.8	
29	Room, floor, sitting position, jeans, short panty >4<	1.1 (1.0–1.2)	81	12.0*/15.1+	12.0/15.1	29.4	09.6	15.2	?	?	*Air + floor
41	Bathroom, LB*, thin nightgown, short panty >4<	1.1 (1.0–1.2)	58	24.1/24.1	23.6/24.6	33.8	03.2	08.8	04.5	05.0	*Immediately after hanging
52	Room, floor, LB, jeans, short panty >4<	1.1 (1.0–1.2)	59	22.0/22.5	22.0/22.5	35.5	01.4	07.0	03.6	04.8	
53	Room, floor, LB, jeans, short panty >4<	1.1 (1.0–1.2)	73.5	15.8/16.0	15.8/16.0	34.5	02.7	08.3	03.2	03.5	
58	Room, floor, LP, naked >3<	1.0 (0.9–1.1)	71	16.5/18.5	16.5/18.5	26.3	13.7	20.1	14.3	16.1	
59	Room, floor, LP, jeans, tights, briefs >5<	1.2 (1.1–1.3)	56	19.8[1]/20.3[2]	19.8/21.0[3]	35.1	01.8	07.4	02.5	04.5	[1] Air, [2] floor, [3] according to police on finding the body
60	Room, floor, LB, jeans, drawers, short panty >5<	1.2 (1.1–1.3)	59	25.4*/26.3+	25.4/26.3	35.1	02.2	07.8	02.5	08.3	*Air, +within recess of cupboard
61	Room, floor, jeans, short panty >4<	1.1 (1.0–1.2)	60	19.3/19.3	18.3/20.3	35.5	00.6	06.2	03.1	03.6	
63	Street, collapsed in front of hospital, after removing clothing the body was stored in a cool room immediately >3<	1.0 (0.9–1.1)	69	5.0*/5.5+	04.5/06.0	28.3	05.6	11.2	06.7	07.1	*Air outside, + air of cool resting room

Table 5 Data of cases with reduced correction factors because of moving air (*LB* lying on the back, *LP* lying in prone position, *LL* lying laterally)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
2	Street, LB on asphalt, jeans, short panty, moving air >2<	0.9 (0.8–1.0)	83	10.9/12.0	10.9/12.0	36.1	00.0	05.4	02.5	03.5	
11	Outside, LB on asphalt, trousers, pants, short panty, moving air* >5<-0.1*	1.1 (1.0–1.2)	60	16.0/16.3	14.0+/16.3	22.1	16.7	25.7	?	?	+According to local weather station for the period in question
25	Room, floor, LB, pyjamas, briefs, temporarily moving air >2</>4<	1.0 (0.9–1.1)	56	15.7/17.2	15.7/17.2	25.4	10.7	17.1	12.9	13.0	
34	Behind entrance door of shop, floor, LB, open trousers, short panty, moving air >2<	0.9 (0.8–1.0)	82	17.1/17.5	17.1/17.5	33.9	03.3	08.9	04.8	05.5	
43	Room, floor, LL, naked, temporarily moving air* >1</>3<	0.9 (0.75–1.0)	67	19.0/21.0	18.0/22.0	34.5	02.1	07.7	02.7	?	*Open windows
55	Street, LL on asphalt, jeans, short panty, moving air >2<	0.9 (0.8–1.0)	80	05.5*/07.2+	05.5/07.2	33.2	02.2	07.8	03.8	05.2	*Asphalt + air
64	Outside LP* on lawn, jeans, short panty, temporarily moving air >2</>4<	1.0 (0.9–1.1)	98	10.3/11.0	10.3/11.0	33.8	03.9	09.5	06.3	06.6	*Found LP, changed LB by emergency doctor
65	Room, floor, LP*, jeans, short panty, temporarily moving air* >2</>4<	1.0 (0.9–1.1)	70	26.4/26.4	25.4/27.4	36.3	00.0	05.6	02.3	02.8	*About 30 min post-mortem and 2 h before examination the balcony door was opened. The position was changed from LP to LB by the emergency doctor
72	Behind open entrance-door of shop, floor, LL, trousers, short panty, temporarily moving air >2</>4<	1.0 (0.9–1.1)	82	17.1/17.5	17.1/17.5	33.9	03.9	09.5	05.1	05.4	

Table 6 Data of cases with reduced correction factors because of moving air and/or wetness and substrates which seemed to accelerate body cooling (*LB* lying on the back, *LP* lying in prone position, *LL* lying laterally)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
1	Apartment house, concrete staircase, LB, jeans, short panty, temporary moving air >2</>4<+>C<	0.9 (0.8–1.0)	67.5	17.6/17.6	16.6/18.6	35.4	00.6	06.2	02.5	02.9	
15	Street, LL, wet track suit trousers, short panty, rain, moving air >14</>15<+>C<	0.7 (0.6–0.8)	76	12.8/12.8	11.8/13.8	35.0	00.3	05.9	04.3	04.5	
22	Outside, soil, LP, wet work trousers, short panty, wind, rain >14<	0.7 (0.6–0.8)	93	09.9/09.9	08.9/10.9	36.2	00.0	04.9	02.7	2.9	
26	Concrete staircase ground floor, LB, jeans, short panty >4<+>C<	1.0 (0.9–1.1)	82	07.3[1]/11.1[2]	04.2[3]/11.1	30.2	06.3	11.9	07.4	07.4	[1]Ground floor near the body, [2]staircase 2nd floor, [3]outside, open front door
28	Street, LB, jeans, short panty >4<+>C<	1.0 (0.9–1.1)	96	-01.1/-02.1	-01.1/-02.1	32.6	03.5	09.1	06.6	06.9	
35	Room, floor, tile, LL, trousers, drawers >4<+>C<	1.0 (0.9–1.1)	69	17.5/17.5	17.0/18.0	33.8	03.1	08.7	03.4*	03.4	*ECG case (Table 1)
36	Apartment house, stony staircase, LP, thicker pyjamas >4<+>C<	1.0 (0.9–1.1)	62	15.6/16.1	15.5/16.5	33.1	03.0	08.6	07.1	08.1	Same scene as 37 (Table 8)
46	Windowless basement room, LP on tiled floor, jeans, bodice >4<+>C<	1.0 (0.9–1.1)	57	22.5/23.0	22.5/23.0	32.8	04.9	10.5	05.8	06.1	Same scene as 47 (Table 7)
68	Staircase. stony soil, leaned back sitting position, pants, open trousers pulled down to knees, moving air >2<+>C<	0.8 (0.7–0.9)	60	15.9/16.3	15.6/16.6	26.0	06.9	15.9	05.7	11.2	

Table 7 Data of cases found on thermally insulating bases (*LB* lying on the back, *LP* lying in a prone position, *LL* lying in a lateral position)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
5	Room, floor, carpet, LB, short panty >3</>4<+>Ap<	1.1 (1.0–1.2)	53	20.8/20.8	19.8/21.8	35.5	00.8	06.4	02.5	03.5	
8	LB on couch, short panty, hip on one side partly covered with blanket, moving air >2<+>Ap<	1.0 (0.9–1.1)	110.7+	18.6/19.3	18.5/19.5	33.4	07.9	13.5	04.8	?	+Underestimated at the scene: 85–95 kg, resulting in a shorter period: 05.9–11.5 hpm
9	Room, LP / LL, floor, carpet, naked >3<+>Ap<	1.1 (1.0–1.2)	68	22.4/23.4	22.4/23.8*	34.0	05.0	10.6	08.0	09.0	*Before examination according to police: 23.8 °C
17	Room, floor, LP on mattress, naked, minimally moving air+ >1<+>Ap<	0.9 (0.75–1.1)	58	22.8/23.9	22.8/23.9	25.9	15.1	29.1	26.8	27.8	
18	Room, LL* on bed, jeans, short panty >4<+>Ap<	1.15 (1.1–1.2)	66	17.3[1]/18.8[2]	15.0[3]/18.8	25.2	15.1	24.1	04.4	26.0	*Changed to LB 2 h before examination [1]in the room near the window, [2]near the body, [3]supposedly at night before finding the body in the afternoon
32	Room, floor, carpet, LB, trousers, moving air + >2<+>Ap<	1.0 (0.9–1.1)	65	17.0/18.0	17.0/18.0	28.1	09.9	15.5	14.0	16.0	+One window open, open door
39	LB on bed, naked >3<+>Ap<	1.1 (1.0–1.2)	37	15.8/15.8	15.3/16.3	31.5	02.4	08.0	04.4	07.9[+]	[+]Unsure
44	Room, floor, carpet, LB, trousers, short panty, moving air* >2<+>Ap<	1.0 (0.9–1.1)	71.5	15.4[1]/21.3[2]	15.4/21.3	35.5	01.1	06.7	03.6	04.3	*Open windows and doors [1]at time of examination beside body, [2]inside cupboards, beneath carpets near the body
47	Windowless basement room, leaned back sitting on a pail with a dust-filled bag, jeans, short panty >4<+>Ap*<	1.3* (1.2–1.4)*	77	same as 46	same as 46	35.5	03.5	09.1	07.3	07.6	Same scene as 46 (Table 6) * The pail with a dust-filled bag seemed to provide stronger thermal insulation
48	Room, LL on sofa with back in contact with back-rest of sofa, blanket between tights, short panty >3</>4<+>Ap<	1.2 (1.1–1.3)	78	27.3/27.3	25.0*/27.3	33.3	08.8	14.4	11.0	14.0	*According to police on arrival at scene 2 h before examination
50	Room, floor, carpet, LB on a bathrobe, tracksuit, short panty >4<+>Ap<	1.25 (1.2–1.3)	72	17.3/19.2	17.3/19.2	29.9	11.6	17.2	15.1	15.6	
51	Room, LB on couch, jeans, boxer shorts, short panty >5<+>Ap<	1.3 (1.2–1.4)	61.5	07.4/10.4	07.4/10.4	34.6	01.6	07.2	03.6	04.1	
54	Room, LL on couch, tracksuit, short panty, moving air* >2<+>Ap<	1.05 (0.9–1.2)	77	21.5/21.5	17.0+/20.0+	29.8	10.5	16.4	04.8	13.8	*Open window. +The open window of the very small room was closed by investigators 1 h before examination. At this time the room temperature was 18.5 °C measured by police

Table 7 (continued)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
56	Room, LL on bed, trousers, short panty, moving air* >2<+>Ap<	1.05 (0.9–1.2)	78	15.7/16.2	10.0+/16.2	26.9	11.2	19.1	04.7	20.7	*The window was open at finding the body 4.5 h before examination. Then it was closed. It was opened again for 30 min a short time before examination and was closed again. +The temperature outside at night before examination at noon was around 0 °C
57	Room, LL on couch, trousers, tights, short panty >5<+>Ap<	1.3 (1.2–1.4)	57	18.7/18.7	18.2/19.2	28.6	11.6	17.2	03.2	18.7	
62	LB on bed, naked >3<+>Ap<	1.15 (1.0–1.2)	60	18.0/20.5	18.0/20.5	27.5	10.9	17.3	13.2	19.7	
69–1	Behind open door of shop, floor, carpet, trousers, short panty, moving air >2<+>Ap<	1.0 (0.9–1.1)	88	16.4/16.4	15.9/16.9	35.5	01.7	07.3	03.1	03.4	Examination at the scene
70	Room, sitting position on thick upholstered couch, back and left region of the lower trunk leaning against thick cushions, pyjamas, pants, in front open bathrobe >5<+>Ap<	1.3 (1.2–1.4)	96	18.0/19.0	18.0/19.0	33.5	08.5	14.1	04.0	17.5	Common scene to 71
71	Room, LL, floor, carpet, pyjamas, briefs >4<+>Ap<	1.2 (1.1–1.3)	64	18.0/19.0	18.0/19.0	26.5	14.4	23.4	17.2	17.7	Common scene to 70

Table 8 Data of cases covered with blanket (*LB* lying on the back, *LP* lying in a prone position)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
6	LB on bed, covered with two thick blankets together about 30 cm thick, night dress, short panty >8</>10<	2.4 (2.0–2.8)*	89	20.6/20.6	19.6/21.6	36.9	02.0	07.6	01.8	15.0	*Because of strong insulation condition and high body weight, adapted according to [3], 1.8–2.5, same scene as 7 (Table 4)
21	Room, floor, LP, short panty, covered with an open eiderdown sleeping-bag >7</>8<	1.6 (1.4–1.8)	78	28.0*/28.0	24.0+/26.0+	30.9	18.1	29.9	?	?	*Measured at examination in the afternoon (early summer time), +according to temperature profile in the room measured by police on next day during the period in question
30	Room, floor, LB, short panty, covered with thin blanket >7</>8<	1.6 (1.4–1.8)	72	18.9/19.9	18.9/19.9	22.5	at least 41.0*		?	?	*0.1>Q<0.2 minimum death time only
37	Room, floor, carpet, thicker pyjamas, disposable nappies >6</>8<	1.5 (1.3–1.7)*	14	15.8/16.3	15.5/16.5	28.3	02.5	08.1	06.8	07.8	Same scene as 36 (Table 6) *there is no experience with disposable nappies concerning the correction factor. The used range was speculated. Because of strong insulation condition and low body weight the *cf* of 1.7 was adapted to 2.2 according to [3]
66	Room, LB on bed, covered with eiderdown until 2.5 h before examination, boxer shorts >8<	1.8 (1.6–2.0#)	116	26.9*/26.9*	26.4/27.4	33.0	24.1	34.2	24.8	?	*Temperature at any place in the near and wider surrounding of bodies # because of strong insulation condition and high body weight adapted to 1.4–1.7 according to [3]
66a	..... Sport shorts >8<	1.8 (1.6–2.0+)		35		27.5	no result[1]		?	?	[1]ambient temperature has been reached, + ...adapted to 1.8–2.5 according to [3], +.... ..adapted to 2.4–3.4 according to [3]
66b	..... Jeans, short panty >8</>9<	2.0 (1.8–2.2+)	18			27.6	not used[2]		?	?	[2]beginning of putrefaction: discoloration of the lower abdominal wall, the method must not be used

Table 9 Data from cases in which the ambient temperature changed within the period in question (*LB* lying on the back, *LP* lying in a prone position, *LL* lying in a lateral position)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
3	Staircase inside a villa, LB partly on blanket, nightdress, open morning gown >4<+>Ap<	1.2 (1.1–1.3)	68	22.4/22.4	22.4/26.0*	33.5	05.4	11.0	?	?	*Before examination according to police 25 °C
10	Dry soil of field path, LB, dump jeans, dry short panty, beginning sleet, wind >2<	0.9 (0.8–1.0)	78	01.5/01.7 (air) 02.0/02.3 (soil)	–01.5/01.5*	16.7	12.1	21.1	03.3	15.0	*According to local weather station for the period in question
13	Room, floor, LB, open trousers, short panty >4<	1.1 (1.0–1.2)	98	19.8/19.8	16.0*/18.0	33.2	07.2	12.8	08.3+	08.3	*Reconstruction of the room temperature by night 1 day later with automatically turned off central heating system. The body was found in the morning +stopped broken wrist-watch
19	Outside, hanging, ground contact of feet only, jeans, short panty >4<	1.1 (1.0–1.2)	112*	13.7[1]/14.6[2]	10.0[3]/13.7	33.8	06.0	11.6	03.4	07.0	*Underestimated at the scene 90–100 kg, resulting in shorter period, 04.6–10.2 hpm [1]air, [2]soil, [3]temperature at night before finding the body at noon
20	Outside, LL on lawn, jeans. short panty, temporarily moving air >2</>4<	1.0 (0.9–1.1)	55	13.3/13.3	10.0*/13.3	28.2	05.6	11.2	02.8	09.8	*Temperature at night before finding the body in the morning
27	Metal road, LL, jeans pulled down to knees, moving air >1<+>C<	0.7 (0.5–0.9)	68	14.2/14.2	07.0*/14.2	30.6	02.8	08.4	01.5	06.3	*Lowest temperature at night before finding the body in the morning
42	Room of attic flat, floor, open skylight*, jeans, short panty >4<	1.1 (1.0–1.2)	57	22.5/22.5	12.8*/22.5	24.8	12.6	33.0	15.4	16.2	*Mean temperature at night outside 12.8 °C (weather station). Examination at noon (summer)
49	Outside, soil, LB, jeans, trousers, leggings, panty, moving air >6</>7<	1.35 (1.3–1.4)	45.5	16.6[1]/ 20.3[2]	13.0[3]/ 20.3	25.4	11.2	21.6	16.3	16.8	[1]Soil [2]air [3]mean temperature at night before finding the body in the early afternoon
67	Metal road, LB, moist but not soaked jeans, tights and briefs, temporary rain, wind >15<+>C<	0.8 (0.7–0.9)	53	12.7/12.9*	10.0+/13.0	26.9	04.9	10.5	09.3	10.3	*Air and soil between stone of metal road +temperatures at night before examination in the morning: 10–12 °C (weather station)

Table 10 Data of extraordinary cases (*LB* lying on the back, *LP* lying in a prone position, *LL* lying in a lateral position)

Case	Cooling conditions	Correction factor (mean range)	Real body weight (kg)	Ambient temperature (°C)		Rectal temperature (°C)	Time estimated limit (hpm)		Time ascertained limit (hpm)		Comments
				Measured	Used		Lower	Upper	Lower	Upper	
4	Room, floor, LB on mattress, covered with feather bed*, short panty without covering >3</>4<+>Ap< with covering >8<	1.5 (1.2–1.8)	63	19.7/19.7	19.7/22.7+	35.9	02.0	07.6	05.8	06.3	*The feather bed was taken off the body 2 h before examination +before examination according to police 22.7°C
31	Outside, soil, LL, remains of burnt clothing, wet body surface, moving air >13<	0.7 (0.6–0.8)	57	06.2*/10.3+	06.2/10.3	33.3	00.3	05.9	03.8	04.3	#Some minutes after extinguishing began, first inflammation of the person with dry fire-fighting equipment, subsequently with water *soil; +air
							2nd measurement 1 h later				
						31.2	01.4	07.0	04.8	05.3	
							method not used				Estimation of the period since death by non temperature-based methods only; see part II
33	LB on bed covered with thick blanket, trousers, boxing shorts, short panty >8</>9<	2.2 (2.0–2.4)	62	18.5/18.5	12.1+	41.6	(04.7	10.3)	00.5	25.5	+On the supposition of malignant hyperthermia with temperature at death of 43.5 °C, subtraction of 6.3 °C from the measured rectal and ambient temperatures as the difference between the assumed rectal temperature at death (43.5 °C) and the 37.2 °C-norm of the formula (nomogram)
						35.3+	not used in report				
38	Room with damage caused by fire, LL, short panty	–	72	-/-	–	–	method not used		03.0	?	Estimation of the time since death by non temperature-based methods only; see part II
40	Found in sitting position on sofa, upper part of the body flexed forward, trousers, short panty >4<+>Ap<+flexed position* Changed 6.5 h before examination into LP on sofa, pulled-down trousers >3<+>Ap<	1.3 (1.1–1.5)	67	11.4/12.9	11.0/13.5	29.2	08.9	14.5	07.5	12.3	*The slumped position reduces the surface of lower trunk for heat exchange to surrounding; the caused deceleration of rectal cooling is assumed to increase the c.f. by about 0,2 units
45	Found outside, head-stand position within large bale of straw, jeans, short panty >??<	1.8? (1.5–2.0?)	83	18.6[1] 11.5[2], 12.2[3], 16.0–18.0[4]		32.8	method not used, no experience as to particular cooling condition		04.5	07.5	[1]Within straw, [2]air at examination, [3]soil at examination, [4]air for the period in question (weather station)
	4 h before examination Outside, soil, LB, jeans, short panty, temporarily moving air >2</>4<	1.0 (0.9–1.1)									Estimation of the time since death by non temperature-based methods only; see part II

pet and clothed with relatively thick pyjamas and a disposable nappy (case 37) a *cf* close to the value used for bedcovers was assumed. Case numbers 6, 37, 66, 66a and 66b are examples where the *cf* chosen according to Table 2 was adapted accordingly [3] because of high insulating conditions and also high or low body weight.

In nine cases in Table 9 the ambient temperature changed to a large extent within the period between death and examination, but the variation could not be recognized from the ambient temperatures measured at the scene by day. Nevertheless, both the situation at the scene and the calculated time since death using the actual ambient temperature measured, indicated in advance that the lower temperature at night had to be taken into account for evaluation of the mean ambient temperature. Where a body was found outside this was apparent from the situation itself. More consideration was required where a body was found in a room (cases 13, 42, and 56 in Table 7).

Extraordinary cases are grouped in Table 10. The cooling conditions were changed after the body was found, but before examination (cases 4 and 40) and therefore wide ranges for the *cfs* were evaluated, taking the cooling conditions into account before and after the change. The very short time of exposure to fire in case 31 did not seem to influence the rate of body cooling.

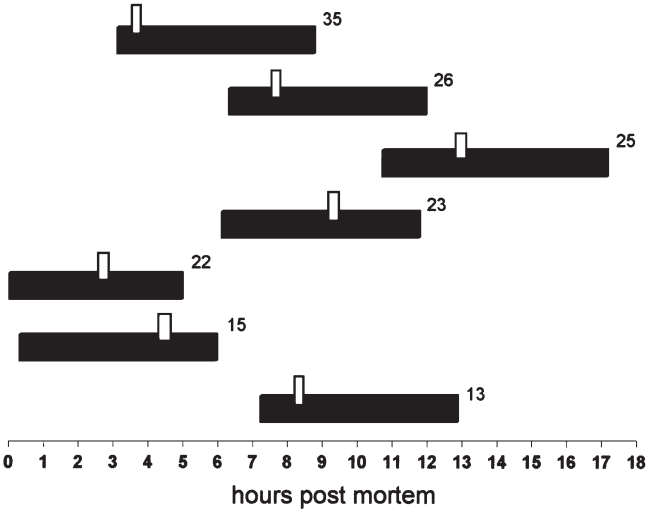

Fig. 1 Exactly ascertained time (*white bars*) and estimated period (*black bars*) since death (hours post-mortem). The numbers to the right of the bars are the case numbers

Length of the estimated period (accuracy)

In 61 out of the 67 cases where the method could be used, the length of the estimated period resulted in the permissible variation of 95% (mode *a* used for calculation) corresponding to the progress of cooling (Table 3).

In six cases (case 16 in Table 4, cases 54 and 56 in Table 7, case 66 in Table 8 and cases 42 and 49 in Table 9) the use of mode *b* for the calculation resulted in a period broader than the permissible variation of 95% but this broader period was used for the evaluation.

Reliability

The reliability of the estimated period since death can be considered only in cases where the time of death could be determined with certainty by the police investigations. In all 60 cases where it was possible both to apply the method and to ascertain the period since death, the estimated period was consistent with the known period (Figs. 1, 2, 3, 4). In 50 cases the estimated period since death corresponded completely to the known period and partially in 10 cases. In those 10 cases where the known and the estimated period were not completely congruent, death could have occurred within the overlapping range between the estimated and the known period.

Effects on the investigative inquiry

It is difficult to determine the effects of the estimation of the period since death on the early stages of criminal investigations and on the final outcome in an objective way. In five cases (nos. 2, 9, 13, 49 and 67) the evaluation of the period since death at the scene seemed to be of vital importance for the investigations. In a further six cases (nos. 17, 21, 43, 48, 55, 58) the evaluation of the period since death seemed to be useful but not vital. In the other cases the estimated period since death coincided with the period as determined by the criminal investigations but had no bearing on the final outcome.

Cases with a common scene

In four cases there were two bodies found at the same scene and the question of the sequence of deaths arose. These paired cases provided evidence for the degree of differentiation which can be achieved with the nomogram method.

In case 7 (Table 4) the circumstances at the scene led to the conclusion that the husband had strangled his wife (case 6, Table 8) manually and then committed suicide by hanging. Despite the very different cooling conditions of the two corpses the resulting estimation of the periods since death coincided. Compared with case 7 the strong thermal insulation and the higher body weight in case 6 compensated for the higher rectal temperature. The nearly fully overlapping estimated periods since death in both cases indicated a short interval between the death of both persons but a conclusion on the sequence of the deaths could not be reached.

In case 36 (Table 6) the husband killed his wife and thereafter his 3-year-old son (case 37, Table 8) and both the sequence and the time period of deaths could be ascertained. Despite the very different cooling conditions and body weights the different rectal temperatures resulted in congruent periods since death.

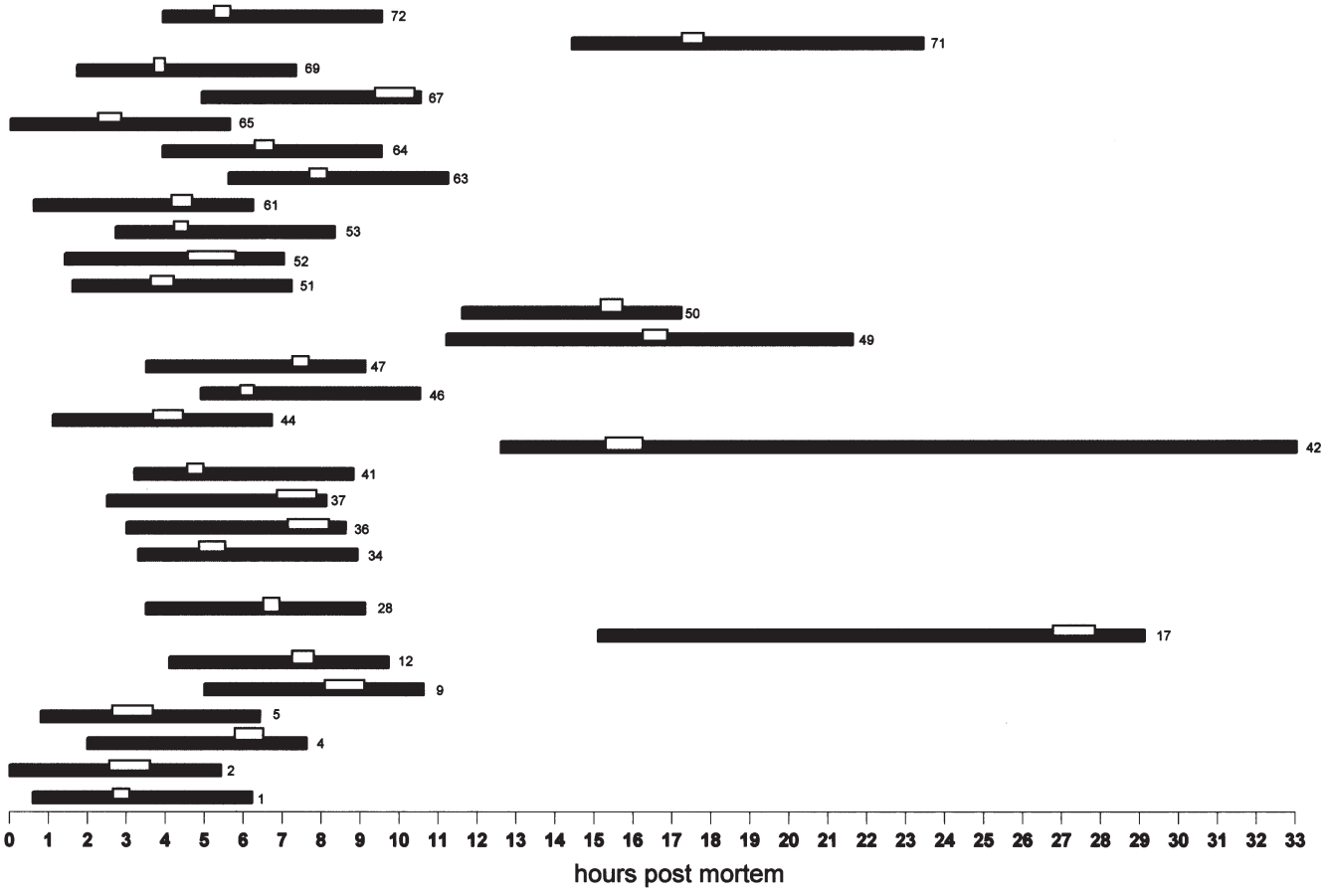

Fig. 2 Time ascertained with an accuracy of up to 1 h (*white* b*ars*) and estimated period (*black bars*) since death (hours post-mortem). The numbers to the right of the bars are the case numbers

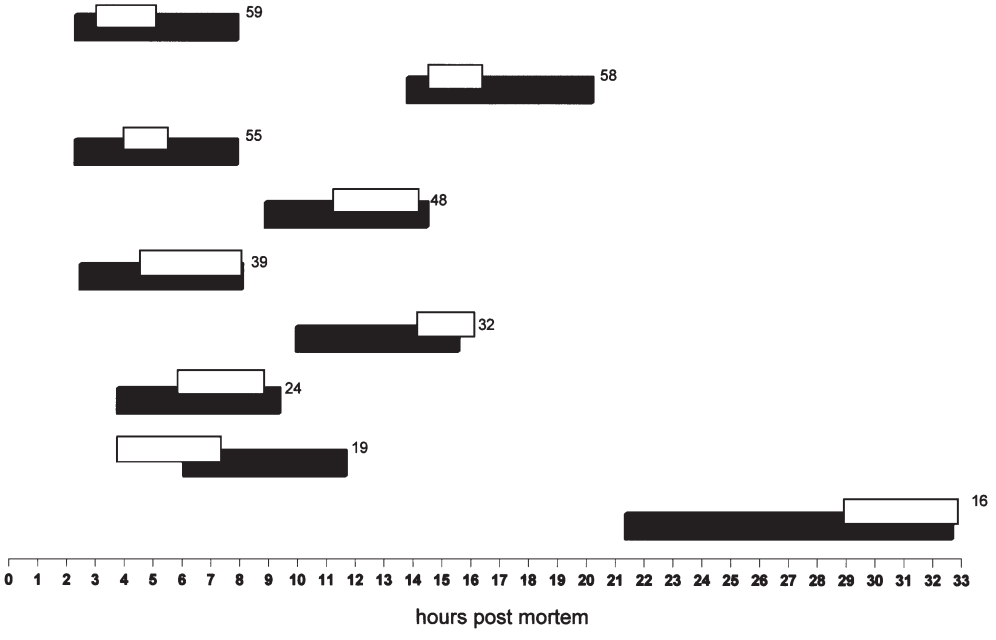

Fig. 3 Time ascertained with an accuracy between 1 and 4 h (*white bars*) and estimated period (*black bars*) since death (hours post-mortem). The numbers to the right of the bars are the case numbers

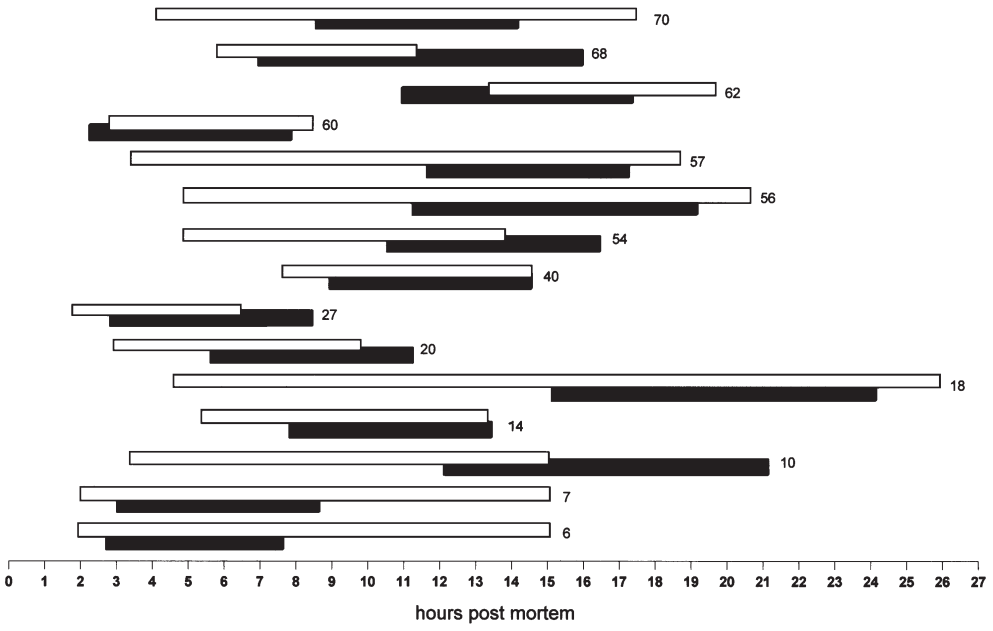

Fig. 4 Time ascertained beyond the interval of 4 h (*white bars*) and estimated period (*black bars*) since death (hours post-mortem). The numbers to the right of the bars are the case numbers

In cases 47 (Table 7) and 46 (Table 6) both the sequence of death and the time since death were known. Despite the very different cooling conditions and body weights, the different rectal temperatures resulted in identical time periods since death.

In case 70 (Table 7) the husband killed his wife (case 71, Table 7), changed his clothes and then committed suicide. According to the results of the investigation, the time of the wife's death could be exactly verified, but the time of the suicide remained unclear. Both the cooling conditions and the body weights of the corpses were different, but in contrast to the other paired cases, this did not compensate for the different rectal temperatures with the result that different periods since death were calculated. The variations of 95% were just outside the permissible level. The question whether the deaths were coincident or in which sequence death occurred was decisive in a lawsuit. Due to laceration of the medulla oblongata (case 70) and the cranial region of the spinal cord (case 71), the deaths occurred within a comparably short time interval after the time of injury. In a case of suicide (case 70) the lack of evidence as to the time of shooting meant that the judgement had to rely on the medico-legal evaluation of the periods since death.

Survival of fatal events

The police investigators were predominantly interested in the time of the fatal event but not in the time of death. Depending on the findings at autopsy and/or toxicology examinations, the evaluation of the period since death was immediately supplemented by an additional evaluation of a possibly relevant interval between the time of fatal injury (cases 8, 20, 21, 30, 38, 40, 45, 57) or ingestion of toxic agents (cases 33, 54, 57, 66) and time of death. In case 21 (Table 8) this aspect was significant as some extravascular migration of polymorphous leukocytes into the subcutaneous fat of the ligature mark provided evidence that the manual strangulation had been survived for a period between 30 min and 3 h.

Discussion

The main problem when using the method in an actual case is to put the correction factor and the mean ambient temperature in a concrete form.

Correction factor

Despite the classification of typical cooling conditions in relation to the scale of correction factors (Table 2), there is still a subjective bias in the choice. Different examiners would choose somewhat different ranges of *cf* for particular cooling conditions for cases such as those given in Tables 6, 7, 8, 9, 10. What would be the consequence of a shift in the order of 0.1–0.2 units in the direction of either higher or lower values? The resulting shift of the estimated period since death depends on the body weight and the progress of cooling. The shift is negligible if the progress of cooling is still low ($Q > 0.5$) and the body weight is not very high. The extent of the shift in cases of high body weight will increase with advanced cooling ($Q > 0.5$; >0.3). The best way to check this in an actual case is to compute the various periods since death resulting from the use of a shifted *cf*.

Mean ambient temperature

The possibility of making an error in evaluating the true mean ambient temperature is greater than the choice of the correction factor, which is exemplified by the cases in Table 9. In case 42 for example, the body was found in an attic flat with open skylights and the mean temperature by night was about 10 °C lower than the ambient temperature actually measured at noon (11.25am) in summer. If this particular circumstance was ignored, the period since death would be greatly overestimated. Even the very broad range of ambient temperatures used (12.8–22.5 °C) was not the best solution as could be seen subsequently from the ascertained time since death of about 16 hours post-mortem (hpm). The air temperature outside was 15.3 °C at the time of examination (inside 22.5 °C) and shortly before the suns rays had heated the room rapidly. By using a mean ambient temperature of about 15 °C, the estimated time since death would agree with the known time exactly. In this case a reconstruction of the room temperature, e.g., by on-line measurement during the following night (as was actually done in cases 13 and 21) was recommended but not carried out. Nevertheless, by means of the range of ambient temperatures actually used, the time of death determined by the investigation was within the estimated period since death but gave a very wide range (12.6–33 h).

The consequence of a slight shift of the ambient temperature towards either higher or lower values depends on the body weight and the progress of cooling as discussed concerning the correction factor.

The risk of obtaining an unreliable result

In every case, the correct use of the method by the investigator is the most important factor. The often criticized uncertainty in choosing both the correction factor and the mean ambient temperature seems to be more a product of inadequate use of the method at the scene. In reality, there is a low risk of obtaining an estimated period longer or shorter than the real time of death by the subjective bias in choosing the ranges for ambient temperature and correction factor.

The method includes some preventive measures against this risk:

1. The permissible variation of 95% (Table 3) was established empirically measuring body cooling under a variety of circumstances. This was broader where a correction factor has been used because of the uncertainty in the order of ±0.1 units [1]. This was confirmed in a multi-centre case study [4, 5].
2. The use of ranges instead of single values for the correction factor and mean ambient temperature for actual cooling conditions.
3. The conservative mode of calculation of the period since death.

Limits and potential of the method

One circumstance where the method must not be used is after transportation of the body from an unknown place to the place of finding. However, case 67 (Table 9) shows that it can occasionally be employed successfully even under these circumstances. The site of death was not the place where the body was found, but it was obvious that the body had been dumped and the mark of a tyre tread pattern was discovered in a puddle beside the body. The area was known for prostitution and drug dealing and the victim was a prostitute. On the assumption that the victim was killed in a car at the place where the body was found, the cooling conditions there could be used for estimation of the time since death by the temperature-based method. The assumption was confirmed by the confession of the suspect. The success of the criminal investigation was considerably supported by the estimated death time at the scene.

The method meets the basic requirement of reliability since it does not claim to offer an unreasonably accurate estimate of the interval since death. In accordance with the international multi-centre study of casework exclusively using the nomogram method [4, 5], the estimated interval of death did not contradict the results of the criminal investigations in any case.

The single measurement of rectal temperature required appears to be practicable at the scene. A further advantage of the nomogram method is the possibility to take individual circumstances into account quantitatively (e.g. ambient temperature, body weight) or empirically (e.g. correction factors) as well as the possibility of taking changes of the cooling conditions between time of death and time of examination into account. The paired cases 36/37 and 46/47 clearly demonstrate the power of the nomogram method to differentiate cases with very different cooling conditions and body weights. They are also good examples of the inadequacies of the antiquated rules of thumb, the longevity of which [9] seems astonishing.

To our knowledge, the use of any other temperature-based method at the scene which might be compared with the results of our field study has not yet been reported in the literature. The results of estimating the period since death by different temperature-based methods [9, 10] including the nomogram method, cannot be evaluated and discussed because of a lack of details (e.g. correction factor used, mean ambient temperature, change of cooling conditions, etc.), which form the basis of the results of the nomogram method. Additionally, these studies did not deal with casework at the scene. Only James and Knight [11] reported errors in estimating the time since death in coroners cases when using the method of Marshall and Hoare [8], on which the nomogram method is based. Since this method was further refined by the nomogram method, the more general analysis of errors [11] cannot directly be compared with the more differentiated analysis of this study.

References

1. Henssge C (1988) Death time estimation in case work I. The rectal temperature time of death nomogram. Forensic Sci Int 38: 209–236
2. Henssge C, Madea B, Gallenkemper E (1988) Death time estimation in case work II. Integration of different methods. Forensic Sci Int 39: 77–87
3. Henssge C (1992) Rectal temperature time of death nomogram: dependence of correction factors on the body weight under stronger thermically insulation conditions. Forensic Sci Int 54: 51–66
4. Henssge C, Knight B, Krompecher TH, Madea B, Nokes L (1995) The estimation of the time since death in the early postmortem period. Edward Arnold, London
5. Albrecht A, Gerling I, Henssge C, Hochmeister M, Kleiber M, Madea B, Oehmichen M, Pollak ST, Püschel K, Seifert D, Teige K (1990) Zur Anwendung des Rektaltemperatur-Todeszeit-Nomogramms am Leichenfundort. Z Rechtsmed 103: 257–278. Cited in [4], pp 97–104
6. Althaus L, Henssge C (1999) Rectal temperature time of death nomogram: sudden change of ambient temperature. Forensic Sci Int 99: 171–178
7. Stipanits E, Henssge C (1985) Präzisionsvergleich von Todeszeitrückrechnungen ohne und mit Berücksichtigung von Einflußfaktoren. Beitr Gerichtl Med 43: 323–329. Cited in [4], pp 80–83
8. Marshall TK, Hoare FE (1962) I. Estimating the time of death. The rectal cooling after death and its mathematical expression. II. The use of the cooling formula in the study of postmortem body cooling. III. The use of the body temperature in estimating the time of death. J Forensic Sci 7: 56–81, 189–210, 211–221
9. Nokes LDM, Flint T, Williams JH, Knight B (1992) The application of eight reported temperature-based algorithms to calculate the postmortem interval. Forensic Sci Int 54: 109–125
10. Baccino E, De Saint Martin L, Schuliar Y, Guilloteau P, Le Rhun M, Morin JF, Leglise D, Amice J (1996) Outer ear temperature and time of death. Forensic Sci Int 83: 133–146
11. James WRL, Knight B (1965) Errors in estimating the time since death. Med Sci Law 5: 111–116