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The forensic relevance of hypothermia in living persons—Literature and retrospective study

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ABSTRACT

In practical case work, forensic experts can be confronted with the problem of estimating cold exposure times in the living given the core body temperature after exposure. However, the current literature lacks systematic studies of body cooling in the living and cooling rates under different circumstances. The objective of our study is to provide working forensic specialists with a collection of cases to use for comparison in order to estimate the accident time or assault time using the cooling rates from similar cases. Excessive data mining led to 18 cases from the literature, 16 cases from Jena's patient files and 9 cases from the database of the Institute for Legal Medicine in Jena. Cooling rates between 0.15 °C/h and 4.1 °C/h were found in adults. Newborns showed rates between 1.2 °C/h and 28.5 °C/h. Potential factors that influence the cooling process in the living are discussed and the possibilities and limitations of the data acquisition and -evaluation are considered.

1. Introduction

In practical case work, the forensic expert can be confronted with the problem of estimating cold exposure times in the living given the core body temperature after exposure. This can be a typical scenario in cases involving violent felonies, accidents or newborn negligence. Also the degree of hypothermia just before death can be of particular interest [1] in some cases. However, current literature lacks systematic studies on body cooling in the living and cooling rates under different circumstances.

There are established models on the post-mortem cooling behaviour of humans [2–5] to support time of death reconstruction. In living persons, who are still capable of thermoregulation, the complex system of homeostatic biological feed back loops like shivering or vasoconstriction severely complicates the development of theoretical models [6]. In addition to body size, nutrition, clothing and ambient temperature further circumstances like injury, intoxication as well as heart and cerebral disease can influence the course of body core cooling.

The purpose of this study was to systematically collect well documented cases of hypothermia with known cold exposure times. This collection of case reports involving accidental hypothermia can provide useful references in the context of forensic questions concerning time of cold exposure and low core body temperature. In order to enable useful comparisons, body temperature and the duration exposure to the cold were examined in association with ambient conditions, injuries, intoxication or underlying disease. Cooling rates were estimated whenever possible.

2. Materials and methods

Two main data sources were used for this study:

- Pubmed/Medline internet resources tool (ca. 21 million articles, ca. 28,000 journals and ca. 1.2 million books)
- Jena University Hospital archives (46,800 files from 2003 to the present)

We restricted our study to case reports and cooling cases with dry cooling conditions. The thermal conductivity is much higher in water than air at the same temperature. Therefore, accidents involving submersion, immersion or cases of people buried under avalanches, were not included. In this study, cases with a documented diagnosis of hypothermia were included, regardless of the different graduation definitions of hypothermia [7,8]. In the following, "cooling" refers to a significant fall of core body temperature below the initial core body temperature of $T_0 = 37.2$ °C. In our heterogeneous sample the core body temperature was measured in different ways, for example rectal, auricular, oesophageal or using a thermometer located in the bladder.

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Table 1
Search criteria (Medline).

Search criteria	Number of results
Cold exposure injuries	415
Hypothermia alcohol	1541
Hypothermia head injury	736
Cold injuries	3218
Hypothermia case reports	1554
Accidental hypothermia case reports	1554
Hypothermia related deaths	285
Accidental hypothermia	18,271
Severe accidental hypothermia	2112
Accidental hypothermia rewarming	1673
Accidental hypothermia treatment	13,145

2.1. Literature survey

An initial exploratory search of "accidental hypothermia" using Medline provided 33,804 hits (completion date 3-12-2011). Using the search items listed in Table 1 including the filters "Language: German or English" and "abstract available" 44,504 publications were found. Table 1 presents the search criteria applied and the numbers of cases found by the specific criterion.

To restrict the amount of results, filters were used to show only items with English or German abstracts. Only those case reports from the literature were included which comprised a documented duration of cold exposure and body temperature. Applying these inclusion criteria 18 case reports with documented core body temperature and the duration of cold exposure could be found.

2.2. Patient data

Patient data from the Jena University Hospital were examined. After analysing all patients treated at Jena University Hospital from 2003 to 2011 about 600 cases with diagnosed hypothermia were found. The sampling interval was chosen because patient data have been saved and processed electronically since 2003. 16 out of the 600 patient files fulfilled the conditions to be included in this collection.

Approximately 70 files with documented hypothermia from 2003 to 2011 are registered in the database of the Institute of Legal Medicine, Jena University Hospital. In the majority of cases hypothermia was associated with falls, intoxication, helplessness and injuries which made it impossible for the individuals to free themselves. After applying the selection criteria of *known time of cold exposure* and *known core body temperature*, 6 cases involving adults and 3 cases of children born at home, were found.

The following list presents the variables collected from each data source provided they were documented (Tables 2–5):

- Sex
- Age
- Body height (not documented in literature cases)
- Body mass (not documented in literature cases)
- Rectal temperature
- Ambient temperature (sometimes documented as minimum and maximum)
- Cold exposure time
- Circumstances
- Intoxication/injury
- Incidence category (categorized by the authors of the present study)
- GCS
- ISS (not documented in literature cases)
- APGAR Score (only newborns)

2.3. Linear regression

We investigated two potential functional relationships using SPSS 19:

(1) Mean cooling rate as a function of the difference between physiological core body temperature T_0 and ambient temperature T_A (Fig. 2).
(2) Difference between physiological core body temperature T_0 and rectal temperature after cooling T_R as a function of the product between exposure time t and $T_0 - T_A$ (Fig. 3). This approach was motivated by the fact that $T_0 - T_R$ rises with increasing exposure time t and increasing temperature difference $T_0 - T_A$.

Table 2
Cases university hospital Jena.

No	Sex	Age	T_R [°C]	Cold exposure [min]	T_A min [°C]	T_A max [°C]	Circumstances	Category (chief cause)	Cooling rate [°C/h]	ISS	GCS	H [m]	M [kg]
J1	F	80	22	1380	0	10	Fall	T	0.65	6	–	1.49	59
J2	F	60	30.4	360	−1	6	Alcohol intoxication	I	1.1	–	8	–	–
J3	F	81	31.5	900	0	8	Fall downstairs	C, T	0.36	–	10	–	–
J4	F	48	31.7	810	5.7	10.2	Alcohol intoxication (1.6‰)	I	0.4	1	15	1.58	50
J5	M	19	33	20	−12.7	0.7	Alcohol intoxication (3.17‰), fall	I	12	2	15	–	–
J6	M	73	33.1	720	1	7	Stroke and fall	C, T	0.32	3	3	–	Obese
J7	M	38	33.9	165	0	2	Alcohol intoxication, fall	I	1.13	1	15	–	–
J8	M	18	34	420	3	14	Alcohol intoxication (1.2‰)	I	0.43	–	15	–	–
J9	F	20	34.3	120	12	21	Att. suicide, paracet. + alc. 2.18‰	I	1.35	–	7	–	ca. 50
J10	F	77	34.3	600	−3	9	Fall downstairs	T	0.27	10	15	1.62	63
J11	M	74	35	720	9.3	19.1	Fall, sleeping outside	E	0.16	–	–	–	–
J12	F	85	35.4	165	−5	−1	Fall	T	0.58	4	13	–	–
J13	M	46	35.5	60	−2.4	9	Paragliding accident	E	1.5	–	15	–	–
J14	M	59	35.7	35	−7	−6	Heart attack, therapeutic cooling	–	2.2	–	3	–	–
J15	M	17	35.8	480	11	22	Sleeping outside	E	0.15	–	15	–	–
J16	M	40	36.4	80	12	26	Fall from height	T	0.45	31	11	–	–

T_R, rectal temperature; T_A, ambient temperature; category/chief cause (I, intoxication; T, trauma; E, exposure; C, central nervous system failure); ISS, Injury Severity Score; GCS, Glasgow Coma Scale; H, body height; M, body mass; cases with central nervous system failure are highlighted.