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"Terminal burrowing behaviour" – a phenomenon of lethal hypothermia

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Abstract Between 1978 and 1994, 69 cases of death due to lethal hypothermia were examined in our Institute. In addition to the common findings associated with hypothermia we especially wanted to examine the so-called paradox reaction which refers to the undressing of persons in a state of severe (lethal) hypothermia. This is obviously the result of a peripheral vasodilatation effecting a feeling of warmth. In our material this paradoxical undressing occurred in 25% of the cases and nearly all exhibited an additional phenomenon which has not yet been described in the literature. Nearly all bodies with partial or complete disrobement were found in a position which indicated a final mechanism of protection i.e. under a bed, behind a wardrobe, in a shelf etc.. This is obviously an autonomous process of the brain stem, which is triggered in the final state of hypothermia and produces a primitive and burrowing-like behaviour of protection, as seen in (hibernating) animals. This phenomenon, which we refer to as "terminal burrowing behaviour", occurred predominantly with slow decreases in temperature and moderately cold conditions.

Key words Lethal hypothermia · Paradoxical undressing · Scene · Terminal behaviour

Zusammenfassung Zwischen 1978 und 1994 gelangten 69 primäre tödliche Unterkühlungsfälle zur Obduktion in unser Institut. Neben den allgemeinen Zeichen der Unterkühlung galt unser Augenmerk insbesondere dem Phänomen der „Kälteidiotie". Hierunter wird das paradoxe Entkleiden von Personen in erheblich unterkühltem Zustand verstanden, offenbar ein Effekt der peripheren Vasodilatation mit der Entstehung eines subjektiven Hitzegefühles. In unserem Fallmaterial trat dieses paradoxe Entkleiden in 25% der Fälle auf. In fast all diesen Fällen zeigte sich aber noch ein weiteres Phänomen, das bisher in der uns zugänglichen Literatur nicht beschrieben wurde. Fast alle Leichen mit teilweiser oder vollständiger Entkleidung wurden in einer Position aufgefunden, die auf einen finalen Schutzmechanismus hinwiesen. Die Leichen lagen unter dem Bett, hinter dem Schrank, in einem Regal etc.. Offenbar handelt es sich hier um autonome Stammhirnprozesse, die im finalen Stadium der Unterkühlung ablaufen und primitives Schutz- oder Höhlenverhalten, wie man es von Tieren her kennt, erkennen lassen. Dieses Phänomen, das wir zunächst „finales Höhlenverhalten" nennen und zur „Kälteidiotie" zu gehören scheint, tritt bevorzugt bei langsamer Abkühlung und moderater Kälte auf.

Schlüsselwörter Letale Hypothermie · Kälteidiotie · Fundortsituation · Finales Verhalten

Introduction

Hypothermia is a rare cause of death in our climate. In most cases of lethal hypothermia elderly and mentally ill persons [20, 26] are affected as well as persons under the influence of alcohol or other substances [e.g. 9, 19, 24, 25].

Although most cases of death from hypothermia are accidental and collectively only amount to a small number of cases they, more often than other types of fatal cases, produce a scene which is at first obscure and difficult to interpret [20]. The reason for the frequent obscurity of scenes at cases of lethal hypothermia is mainly due to the phenomenon of the so-called paradox reaction [8, 10, 14, 23, 49]. In many cases the bodies were found partly or completely unclothed and abrasions and haematomas are found on the knees, elbows, feet, and hands [8, 23]. At first sight these observations would strongly indicate a crime, as very often a female body in a state of undress raises the suspicion of a sexual attack. As a consequence the public prosecutor demands an autopsy to clarify the cause of death. The police expect clues for their investigations, but the diagnosis of lethal hypothermia is very difficult to determine. For this reason we reviewed all

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deaths due to hypothermia which occurred in our Institute during the years 1978–1994, with special reference to the so-called paradox reaction to cooling. During this survey we found a phenomenon which seemed to be combined with the paradoxical undressing. In some cases the bodies were found in strange situations, i.e. lying under a bed, behind a wardrobe, or in a shelf, etc. indicating that the final positions were a kind of self-protective burrowing-like behaviour. As no corresponding observations could be found in the literature, we called this phenomenon "terminal burrowing behaviour".

Physiological aspects of hypothermia

Humans – like mammals – are homoiothermic beings and heat (energy) formed by the regulatory mechanism is dispersed [2, 5]. Additional heat to maintain the body temperature can be produced by a) voluntary changes of behaviour (change of locality, additional clothes, voluntarily increased exercise etc.), b) shivering and c) chemical thermogenesis (an immediate increase in the rate of cellular metabolism). The processes b) and c) are autonomous thermoregulatory reactions. In adults a) and b) are the main reactions against cooling, in newborns c). An essential source of non-shivering thermogenesis is the brown fatty tissue which is rich in mitochondria and mainly found in infants.

Regulatory thermogenesis is triggered at ambient temperatures below the limit of the so-called thermic neutral zone (lightly clothed adults, ambient temperature 26–28° C, calm winds, 50% humidity) [5, 20]. The thermoreceptors of the skin, which are responsible for the stimulus of cooling, transmit the impulses mainly over the posterior white columns to the anterior and posterior hypothalamus, where the main integrative processes are carried out [11, 20]. There exist direct afferent connections between the thermoreceptors of the skin and the respiratory centre. The distribution of the thermoreceptors in the skin and/or the threshold value of the temperature initiating thermogenesis differs regionally. Cooling of the face will not start a major regulatory thermogenesis but a decrease of temperature of the trunk or the extremities will [5].

Shivering is triggered by a tract caudal to the posterior hypothalamus and is connected to the centre of the motoric system. Non-shivering thermogenesis (brown fat) is triggered by sympathetic tracts by adrenergic β-receptors. Blood vessels of the skin are able to react directly to thermal changes, mainly through a local sensitivity of the muscles of the vessel walls [5]. At very low ambient temperatures the heat production in the body can be increased to a level tenfold that of the basal metabolism by a maximum of voluntary activity [5]. In contrast the autonomous thermogenesis only results in a three to five fold increase [5]. Below the limit of the triggering range there exists a high risk of lethal hypothermia, especially during physical inactivity.

Pathophysiological aspects of hypothermia

The general cause of lethal hypothermia is a) the so-called environmental hypothermia due to low ambient temperatures and occasionally exhaustion, where the bodily loss of heat exceeds production, b) cold environment and toxic effects, and c) diseases which reduce resistance [3, 5]. Congelation is a special form of hypothermia leading to the formation of ice crystals in the cells.

Factors which increase sensitivity to cold are age, arteriosclerosis, liver cirrhosis, pancreatitis, endocrinopathy, anterior pituitary insufficiency, Addison's disease and many others. Decreasing environmental temperatures initiate the first defence mechanism (e.g. voluntary change of behaviour, shivering, peripheral vasoconstriction). At body temperatures of 28–32° C impairment of cerebral functions is manifested in analgesia, clouding of consciousness, hallucinations, and slowed reflexes [3, 6, 20, 37]. There are no specific morphological changes. Besides the nonspecific findings such as dilatation of the right heart ventricle and edema of the lungs, necrosis of the pancreas, erosion of the gastric mucosa, disseminated edema, miosis, decreased breathing frequency and cardiac output, mild acetonaemia and metabolic acidosis can be found [20]. Characteristic changes in the ECG can also be found [1, 36, 45].

Case findings

In the period between 1978 and the first half of 1994, 69 autopsies of fatal cases due to hypothermia were performed in our Institute (55 males and 14 females). After our autopsy findings together with the police investigations, all these cases were declared to be accidental. In another 35 cases hypothermia was a concurrent of death, mainly in connection with intoxication, drowning, cardiac disease, or severe injury [29].

The scene

In 33 cases the bodies were found in buildings and in 31 cases the bodies were found in the open (Table 1). In 17 cases (25%) ([23]: 17%, [43]: 75%) the bodies were found inadequately clothed (n = 12) or completely naked (n = 5) [8, 10, 14, 23, 49]. In most cases, the clothes were strewn on the ground beside the body, sometimes forming a trail of scattered clothing over a distance of some metres. Although there was no homogenous pattern of undressing, it seemed that the undressing in most cases had started with the lower half of the body. In 14 of the 17 cases with undressing, the bodies were found lying in a position which indicated a "terminal burrowing behaviour". In 3 cases the bodies were found in a public park under a bench. In another 3 cases the bodies were found in large rooms such as workshops and cellars, which were more or less empty. The bodies were found in a corner of

Table 1 List of locations where victims of lethal hypothermia were found during 1978–1994 (n = 69)

Scenes	n
a) In buildings (n = 33)	
apartment	17
cellar	7
staircase	3
garden house	3
workshop	2
aircraft hangar	1
b) In the open (n = 31)	
public park	12
forest	7
lawn	6
street	3
bus stop	3
c) Other (n = 5)	
tent	2
car	2
subway tunnel	1

the rooms in the fetal position. In 5 cases the bodies were found in apartments: 3 bodies were lying under the bed (Fig. 1 a und b), and in 2 cases behind a wardrobe. In 1 case a mentally disturbed woman entered the cellar of a house where she was locked in accidentally and was found dead lying on the lowest board of a shelf behind a tyre (Fig. 2 a and b). In another case an intoxicated man was unintentionally locked in an aircraft hangar and later found between several barrels. Finally, in 1 case a 19-year-old mentally disabled man, who had run away from home was found in a forest, lying in a naturally formed depression in the ground. In all cases exhibiting this "terminal burrowing behaviour" there was also a partial or, more often, complete paradoxical undressing, and 12 of these 14 cases (86%) showed abrasions on prominent parts of the body (e.g. knees, elbows, etc.). Furthermore, in cases of lethal hypothermia, many (n = 31; 45%) of the bodies were found in a prone position which in most cases was an extended prone position with the forearms drawn up near the chest. In 10 cases (14%) the bodies were found in the fetal position. In comparison with comparable groups of different causes of death (myocardial infarction: 10%, intoxications: 17%, all cases of our material of the years 1983–1989 [n = 1699]: 10%), the prone position was significantly more frequent in fatal cases due to lethal hypothermia (45%) than it was in other cases.

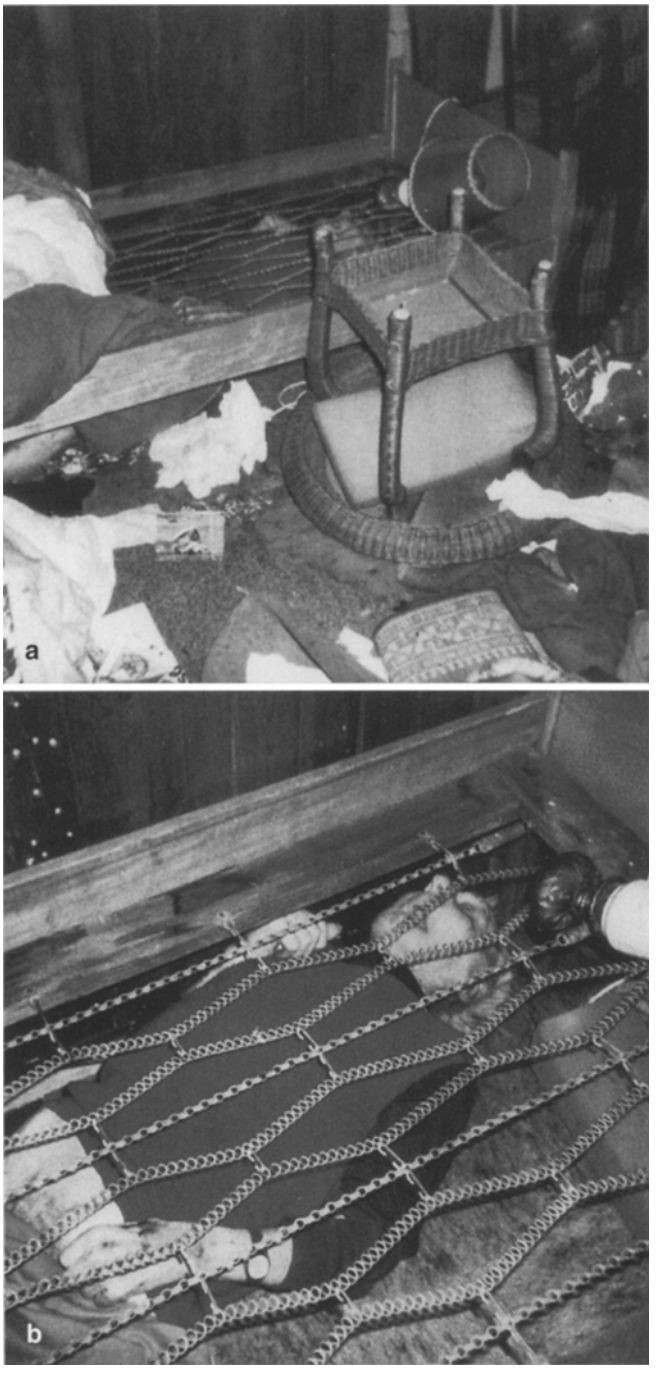

Fig. 1 **a** Case 1 – A 91-year-old man was found dead by his son in his garden shed, the furniture in disorder. In a corner of the room the body of the man, lying on the floor under a bed. **b** Case 1 – The body of the man was found under the bed, from which the mattress had been removed. The lower half of the body was undressed

Autopsy findings

By external inspection of the bodies the 2 main findings were red-purple blotches [7, 8, 20, 22, 27, 41] and abrasions [8, 23]. Red-purple blotches and bluish discolorations of the skin in non-hypostatic prominent areas were found in 48 cases (68%) ([44]: 43%, [23]: 60%, [13]: 72%, [12]: 75%), predominantly at the knees (n = 65; 94%), elbows (n = 58; 84%), wrists (n = 37; 54%), and more rarely in the face and on the hands (n = 7; 10%). It was remarkable that these discolorations predominantly developed on those parts of the body which were not covered with clothing (82%). The histological examinations of these redpurple blotches showed only nonspecific findings such as edema, hyperaemia and sometimes focal inflammatory cell infiltrations [20, 35].

Fig. 2 **a** Case 2 – A 37-year-old woman was found dead in the locked cellar of a cleaning company. The body was "hidden" in the lowest shelf of a steel storage shelf behind a spare wheel. **b** Case 2 – After removing the wheel it was determined that the lower half of the body was undressed. The clothing was found lying nearby the body on the floor

Fig. 3 Case 3 – A 54-year-old man was found dead in his appartment, completely unclothed. There were abrasions on both knees, red-purple blotches, and bluish discolorations. Traces on the floor indicated that the man had crawled for some metres in the appartment

Abrasions [8, 23] were seen in about half of all hypothermia cases (n = 34), but in 86% of the cases with "terminal burrowing behaviour". Histological examinations revealed that the abrasions were obviously formed recently before death, and were caused by crawling around [8, 43, 46]. When these abrasions occurred, they were mainly seen on the knees (100%) (Fig. 3), elbows (92%) and hands (80%), and more seldom on the back of the feet (24%) and in the face (15%) (Fig. 4). Erosions in the gastric mucosa, Wischnewsky-ulcers [25, 50], existed in 59 cases (86%) ([23]: 40%, [12]: 79%, [25]: 72%, [28]: 86%, [13]: 88%, [44]: 91%, [50]: 91%). Necrosis, hemorrhages, and acute inflammatory reactions of the pancreas were seen in 16 cases (23%) ([23]: 7%, [40]: 10%, [19]: 18%, [12]: 33%, [10]: 38%, [28]: 67%). These findings in the pancreas were manifold [28]. Here the pattern of changes obviously depends on the duration of exposition to the cold. Striped haemorrhages within the iliopsoas muscles [7, 41] were found in 8 cases (12%) ([23]: 10%).

Histologically, a basal lipid accumulation in the epithelial cells of renal proximal tubules was impressive [44] and could be demonstrated in 45 (65%) cases ([44]: 91%). The distribution of the lipid droplets within the tubules

Fig. 4 Case 4 – A 65-year-old woman was found dead in a public park behind some bushes. There were abrasions on the skin of the face, the knees and the feet

was irregular and was only observed partly in single tubules, and partly in groups of tubules. In every case all epithelial cells of a tubule were affected, and always the basal parts. Compared with control cases from our autopsy material, the basal lipid accumulation in the epithelial cells of the renal proximal tubules is a valid factor for the diagnosis of lethal hypothermia because other cases such as electrocution ($n = 20$): 5%, hanging ($n = 20$): 5%, running over by a train ($n = 20$): 0%, bleeding to death ($n = 20$): 0%, exhibited a significantly lower incidence, with the exception of fatal cases due to primary cardiac failure where it was seen in 20% of cases.

Other findings occasionally described for hypothermia such as release of the cortex of the suprarenal glands [23, 31] and thyroid gland [23, 42, 48], or infarctions of the viscera [4, 27, 33] showed no significant differences in their appearance compared to control groups.

Toxicology

Alcohol consumption plays an important role in cases of lethal hypothermia [9, 19, 24, 25]. In our case material 41 cases (59%) showed alcohol levels of 1.0‰ or more ([24]: 59%, [23]: 50%, [25]: 73%). Besides alcohol the benzodiazepines were the second largest group of intoxicants found (Table 2), but in all cases the concentrations were within the therapeutic range.

Table 2 Toxicological findings in cases of lethal hypothermia: 1978–1994 ($n = 69$)

Toxicological findings	n (%)
Alcohol	41 (59)
Benzodiazepine	8 (12)
Barbiturate	6 (9)
Opiate	4 (6)
Amphetamine	1 (1)
Cannabinoide	1 (1)
Phenothiazine	1 (1)

Another valid factor in the diagnosis of lethal hypothermia is the increase of acetone in serum [12], and in 40 cases (58%) ([12]: 38%) we found acetone concentrations between 10 and 190 mg/L serum.

Discussion

In cases of lethal hypothermia the suspicion of crime is often raised when the so-called paradox reaction occurs [8, 10, 14, 23, 49]. Here the bodies of the hypothermia victims were found partly or completely unclothed. The reason for this paradoxical behaviour seems to be the effect of a cold-induced paralysis of the nerves in the vessel walls, which leads to a vasodilatation, giving a feeling of warmth. Another theory proposes that the reflex vasoconstriction, which happens in the first stage of hypothermia leads to paralysis of the vasomotor center giving rise to the sensation that the body temperature is higher than it really is and in a paradox reaction the person undresses [3, 21, 30, 32, 34].

In addition to paradoxical undressing, we observed another phenomenon which could strengthen the suspicion of a crime and always seemed to be linked with paradoxical undressing. In 20% of our cases of death due to hypothermia the bodies were found in a position, which at first induced the suspicion of an attempt to hide the body. But after all our examinations together with the police investigations it was clear that no other person was involved. Obviously the strange positions in which the bodies had been found, were the result of a (pre-)terminal behaviour, which – for lack of comparable descriptions in the literature – we have called "terminal burrowing behaviour". The discovery positions always gave the impression of a protective burrow-like or cave-like situation, as the bodies were found under the bed, behind the wardrobe, in a shelf etc.. The clothes of the bodies were always strewn on the ground in front of the final position, sometimes forming a trail. In every case the paradoxical undressing had obviously happened before this self-protective "burrowing behaviour". This is sustained by the fact that the removed clothing was never found at the final position where the body was found, and some of the vic-

tims due to cooling had obviously been crawling around [8, 43, 46]. In most cases the final position in which the bodies were found could only be reached by crawling on all fours or flat on the body, resulting in abrasions to the knees, elbows, etc. [8, 23] (Figs. 3 and 4). This crawling to the final position seems to have happened after undressing as there were abrasions to the skin but no damage to the corresponding parts of the removed clothing.

Apparently this finding is the result of a terminal primitive reaction pattern which is probably an autonomous behaviour triggered and controlled by the brain stem. It seems to be an act of getting out of harm's way and into safety. Also a state of severe mental confusion, which obviously plays a role in cases of hypothermia [3, 6, 37], seems to be a factor. This behaviour probably occurs with the objective of reaching a state of common safety rather than specifically to bring the body into warmth. Otherwise it is not understandable why the victims of hypothermia prefer to enter a cold steel shelf or lay on a cold stone floor, rather than putting their clothes on again.

This "terminal burrowing behaviour" only occurred in 20% of our cases of death due to hypothermia. As in other findings of hypothermia [19, 41, 46] this phenomenon also seems to be dependent on how fast the body temperature decreases. Moderately cold ambient temperatures and a slower decrease of the body temperature induced a "terminal burrowing behaviour" more often than environmental temperatures far below 0° C with a rapid state of severe hypothermia. There was no significant effect from alcohol or other substances on the occurrence of the paradoxical undressing or the "terminal burrowing behaviour".

There are many publications concerning hypothermia, but none specifically describe what we have called "terminal burrowing behaviour" and most describe the morphological findings only. On the other hand Kinzinger et al. [23] reported the bodies of 2 completely undressed males who died due to hypothermia in a public park. Both were found in a prone position with the arms close to the body, one directly under a bench, the other just in front of it. This clearly shows the situation, which we have described above as "terminal burrowing behaviour", but the authors did not elaborate on this.

Following our assumption, that the "terminal burrowing behaviour" is a primitive response pattern of the brain stem, there should be some parallels in the animal world. Unfortunately there are hardly any publications about animals dying due to hypothermia, but there exist numerous papers on hibernation. A variety of mammals counter the problem of increased thermoregulatory energy demands by means of deep hibernation or daily torpor [17, 38, 39], in which they reduce their energy requirements to a fraction of their euthermic metabolic rate [16, 17, 38, 39]. Hibernators retreat into their hibernaculum, e.g. a frost-protected cave or burrow and relinquish most of their behavioural and territorial activities [15]. In addition the enery benefits and costs of a certain thermoregulatory pattern can be influenced by social interactions [16]: energy savings by torpor in Peromyscus leucopus are improved when mice huddle together in groups [47], or as with alpine marmots which form groups of approximately 20 animals in special winter burrows [18].

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