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Case report

# Fatal heat stroke in a child entrapped in a confined space

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ABSTRACT

We report the case of a child succumbing to heatstroke caused by confinement in an icebox. The post mortem examination found cyanosis and hematomas indicating that the child had tried to get out of the container. The temperature of the body was higher than it should have been considering the rigor and delay before post mortem examination. The autopsy showed no significant injury and toxicological tests were negative. A physiological study etablished that death resulted from heatstroke, not a lack of oxygen or $CO_2$ poisoning. We conclude that heat stroke should be considered as a possible mechanism of death even in the absence of context of environmental hyperthermia. We recommend that in these situations involving confinement, establishing the mechanism of death should be done not only on the basis of a detailed post-mortem examination to rule out other causes of death, but also based on complete physiological investigations.



## 1. Introduction

In the absence of simultaneous traumatic or medical causes, the mechanism of death due to confinement in a closed space is usually oxygen asphyxia. Few articles have reported heatstroke as a possible cause of death in this type of situation, especially in the absence of an overheated environment.[1,2] In forensic medicine, the diagnosis of heatstroke is difficult to establish because there is little specific evidence for this diagnosis at autopsy,[3–5] although several medical articles outline pathophysiological explanations for understanding the mechanism of death.[6–9] Even fewer forensic cases have been published concerning children. Most cases of fatal heatstroke occur after exposure to environmental hyperthermia. This is the case with children left in a car in direct sunlight,[10–12] and some authors have taken into account calculations of thermophysiology.[11] In these situations, the diagnosis of hyperthermia is easily evoked because of the high temperature found in the car at the time of death. Other cases of heatstroke have been reported due to fatal hyperthermia in bed, especially in cases in which children were excessively covered,[10,13–15] or in which electric blankets were used.[15,16] A similar mechanism of death by heatstroke has been described in a newborn due to the malfunction of his incubator.[17] However, cases of death from heatstroke occurring in the absence of initial environmental hyperthermia are exceptionally reported. De Jong[2] published the case of an adult victim of sudden fatal heatstroke after being locked in a turned-off refrigerator, and De Giorgio[1] that of a schizophrenic adult with pneumonia, locked in the wardrobe of his hospital room. No such cases have been described in a child.

We report here, for the first time, a case of fatal heatstroke in a child confined inside an unpowered icebox. Our aim is to show that hyperthermia is a possible mechanism of death in cases of confinement, even though the mechanism of death could initially be considered as $O_2$ deprivation or $CO_2$ poisoning. We relied on medico-legal evidence based on a detailed post-mortem

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examination, associated with comprehensive environmental and physiological investigations.

## 2. Case report

A six year-old boy, with no known physical or mental disease, was found dead at around 5:00 am on morning in early September. He was found in an icebox (120 × 81 × 82 cm) placed in a van belonging to his parents. The child had last been seen playing with his 4 year-old sister between 5:00 and 6:00 pm the evening before. When his parents did not see him after that, they concluded that he was at his grandparents' flat, one floor above theirs. The investigation showed that while playing, he likely voluntarily entered into the box the night before, and was not able to get out after closing the door. Once closed, this door could not be opened from the inside. These two children were often left to themselves, sometimes playing for long periods of time without adult supervision.

The external examination of the body at 8:30 am (3:30 h after his discovery) showed that the child measured 125 cm in length. He was thin, weighing in at 20 kg. He was nearly naked, wearing only a pair of underwear and flip-flops. He showed signs of having bled through the orifices of his face, had marked cyanosis, a total non-set livor mortis, rigor mortis, an anal temperature at 34 °C but no conjunctival petechiae. The ambiant temperature (in the closed empty box and in the garden) was measured at 22 °C. Purplish bruises were found located on the posterior side of the left forearm, left knee and back along his spine. No injuries were observed on his feet. A whole body scanner revealed no specific injuries, and in particular no traumatic lesions. The autopsy found bruising under the skin of the back on the spinal processes, and the posterior side of both forearms, which may indicate that the child had tried to raise the alarm and excape from the refrigerator. We did not observe any sign of natural- or abuse-related injury. There was no evidence of intrathoracic petechiae, but congested and edematous lungs and cerebral edema were observed. At H24, the child had a diffuse green abdominal stain despite a conservation temperature of +4 °C, more diffuse that what is usually found after a similar post mortem lapse of time.

Systematic toxicological analyses were performed; procedures included headspace gas chromatography-mass spectrometry (GC-MS),[18] high performance liquid chromatography-photodiode array detection (HPLC-PDA),[19] UHPLC-PDA/MS,[20] UHPLC-MS$^2$ screening,[21,22] as well as immunoassay techniques and a carbon monoxide assay. No molecule of toxicological interest was detected in the post-mortem samples of the victim. A peripheral blood sample was analyzed and found a myoglobin level of 2629 μg/L (normal values < 100 μg/L), an ACTH level of 0.2 pmol/L (with a normal range of 1.6–13.9 μg/L), and a CRP level of less than 5 mg/L (normal value < 5 mg/L). In the vitreous, sodium and chloride concentrations were 142 and 123 mmol/L respectively (with normal values < 145 and < 105, respectively).

Histological examination revealed mechanically induced asphyxia lesions as evidenced by alveolar distension and multiple ruptures of the inter-alveolar septi (acute emphysema) on top of alveolar edema and congestion. Food particles were found in the bronchi and the bronchiolae, suggesting they played a part in the asphyxia. The examination of the brain showed few pronounced signs of anoxic lesions. No anomaly of the heart was found. The bruises of the limbs and back were concomitant with the time of death.

At the end of these investigations, the exact cause of death could not be identified. In particular, asphyxia being a non specific symptom, it could not formally be linked to a precise pathological mechanism. Police and environmental investigations did not show evidence of active abuse or suicidal behavior. The available data suggested the child had died accidentally after being unable to escape the icebox that he had climbed into alone. The potential causes of death in this case were asphyxia due to a hypoxic atmosphere, positional asphyxia, lung inhalation or possibly heatstroke.

## 3. Discussion

Heatstroke is characterized by an elevated core body temperature (>40 °C) and a dysfunction of the cerebral thermoregulatory system.[4,23] In the literature, hyperthermic death is quite often reported[7,24,25] when a subject is exposed to high temperatures or during intense physical activity in a hot environment. Among children, cases of fatal heatstroke usually occur when they are locked in cars in direct sunlight[10–12] or when they sleep in overheated beds.[10,14–17]

To highlight the probable cause of death of this victim, we considered the various parameters theoretically at play in such situations of confinement: the alteration of $O_2$ and $CO_2$ levels, the increase in air temperature and relative humidity within the container, and the increase in body temperature.

The initial volume of air in the container was about 800 L, with an initial volume of $O_2$ (expressed as a percentage) in dry air of 21%. According to physiological data in children,[26] maximal oxygen consumption ($VO_2$max) would be expected to be about 0.7 L/min in the current case. When the proportion of oxygen in the air falls to 10%, nausea, vomiting, inability to move or cry out can occur. Below 6%, seizures and gasping can occur, followed a few minutes later by heart failure.[2]

The normal volume of $CO_2$ in dry air (expressed as a percentage) is 0.04%, and exhaled air contains 4% $CO_2$. On average, a 6 year-old child will exhale 0.2 L/min $CO_2$ at rest, and 1.7 L/min $CO_2$ in conditions of maximum ventilation. Distress occurs when the proportion of $CO_2$ in the air increases: at 7% proportion of $CO_2$ in air, consciousness is slightly altered, but at 15% fainting may occur.[27] It is well known that hypoxia associated with hypercapnia can result in acute respiratory distress syndrome, the $CO_2$ significantly potentiating hypoxic hypoxia-induced death. Nevertheless, there are very few reports and data on their distinctive role.

Considering that the unpowered icebox was thermally insulated, any body heat produced would remain inside the container. Nevertheless, the seal on this type of icebox is never completely airtight, so perfect temperature stability remains improbable. An estimate of the temperature increase inside the container was calculated on the basis of metabolic heat production, with about 0.24 KCal required to increase by 1 °C the temperature of a 1000 L volume of air. Calculations of child body temperature are based on known values for average specific body tissue heat and presumed rate of metabolic heat production. In our case, 16.6 Kcal were required to increase body temperature by 1 °C.

Relative humidity inside the icebox was estimated at 65%. We can estimate that with agitation, the victim eliminated 80 ml of sweat in 5 min.

The box did not contain any toxic gas or other substance that might lead to a chemical reaction or death by poisoning. Considering the physiological basis established above, we can assert in this particular victim's case, that:

1 To reach a $O_2$ percentage of 10% and 6% in air, a child might consume 88 L and 119 L respectively of $O_2$ trapped inside the box. Thus, he required between 10 h 45 min and 14 h at rest, or between 2 h and 2h50 min of intense physical exertion to achieve these results (Fig. 1A).
2 To reach a $CO_2$ percentage of 7% and 15% in air, between 4 h 30 min and 10 h were required to exhale 56 L–119 L of $CO_2$ respectively into the container at rest, and between 32 min and 1h10 min, if he was agitated (Fig. 1B). These numbers indicate