Forensic Science International: Reports 8 (2023) 100342

Contents lists available at ScienceDirect

Forensic Science International: Reports

journal homepage: www.sciencedirect.com/journal/forensic-science-international-reports

Artifacts in postmortem CT-imaging of the brain: A cooling effect?

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ARTICLE INFO

Keywords:
Postmortem computed tomography
PMCT
Brain CT
Freezing
Cold
Postmortem magnetic resonance
PMMRI
Autopsy
Postmortem imaging

ABSTRACT

We would like to present two cases of middle-aged men found dead outdoors, in relatively low temperatures, whose postmortem brain CT scan exhibited unusual findings. Both cases presented traumatic injuries, mainly cerebral (bleeds, contusions). The first case involved a 55-year-old man, found dead in front of his house, mostly covered by snow, with an ambient temperature reaching − 1.8 °C. Before the autopsy, a native (without contrast) postmortem CT scan was performed which revealed a linear delimitation between the anterior and posterior regions of the brain, along with hypodensity in the anterior region, compatible with an advanced state of decomposition. The second case involved a 77-year-old man, found dead on the bottom of a cliff where his car was found. Temperatures recorded then approached 9 °C. However, a technical glitch in the cooling cell during the storage of the corpse was reported. The subsequent postmortem CT scan performed before the autopsy showed a grossly circular zone of hypodensity across the periphery of the brain with a centro-peripheral and right-left gradient. Furthermore, macroscopic and microscopic examinations of the brain didn't reveal any pathological findings concerning the density differences observed on imaging in both cases. These two cases seem to highlight the processes through which the cold might affect brain tissue and his appearance on imaging, which could consequently represent a potential pitfall in postmortem forensic investigations. We intend to encourage further studies on this topic, to allow correct interpretation of such CT scan findings in forensic cases, and to open the debate about the possible causes of this phenomenon.

Introduction

Postmortem changes along with the decomposition process begin immediately after death. The rate and extent of these changes are directly influenced by the external environment surrounding the corpse, e.g. ambient temperature, wind, humidity level, burial, depth of burial along with access by insects [1,2]. In addition, other variables concerning the body itself are to be considered, such as the cause of death, body size, weight and temperature, clothing etc. [1,2]. Ambient temperature appears to have one of the greatest impacts on the decomposition rate of a corpse [3]. One of the earliest radiological signs of decomposition is cerebral autolysis, characterized by loss of definition of the gray-white matter junction, decrease in cerebral attenuation, and effacement of the sulci and ventricles [1,4].

Nowadays, postmortem computed tomography (PMCT) has become fully integrated into the routine work of forensic pathologists in a lot of forensic institutes, as an asset in the preliminary evaluation of each corpse subjected to a medico-legal investigation [5–8]. A PMCT is indicated in many different forensic contexts to try to establish the cause of death, such as for example traumatic deaths due to its excellent detection of skeletal traumatic lesions as well as to reconstruct a trajectory in ballistic or sharp force cases [5,9,10]. In addition to the valuable detection of air (hardly detectable in a conventional autopsy setting), it can also serve as a guide for focused dissection in the

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https://doi.org/10.1016/j.fsir.2023.100342
Received 19 July 2023; Received in revised form 6 October 2023; Accepted 9 October 2023
Available online 11 October 2023

subsequent autopsy (e.g. vascular injury) and allow preparation for unexpected autopsy findings (e.g. foreign objects) [11]. The current protocol regulating the practice at our center dictates that each body entering our institute following a request by the public prosecutor for a complete forensic autopsy undergoes a full body native (without contrast) CT scan with specific acquisition for the brain parenchyma (Table 1), preferably without previous manipulation. External environmental factors influencing the decomposition process may consequently also affect postmortem radiological findings [1].

In light of their potential influence on postmortem changes, adequate consideration of the aforementioned external factors is therefore paramount to achieve valid conclusions. Through this manuscript, the authors would like to present two cases exhibiting peculiar findings on postmortem CT imaging, probably due to cold temperatures.

Fig. 1. General view of the body mostly covered by snow.

Case reports

Case 1

The first case presented involved a 55-year-old man who was found dead in front of his house, laying in a supine position, and mostly covered by snow (Fig. 1). The forensic pathologist called on-site recorded an ambient temperature of approximately − 1.8 °C (28.8°F), in alignment with the rectal temperature measured at about 0.6 °C (33.1°F). The time of death was estimated to be more than 24 h. Police work later retrieved a last contact dating to ten days before the discovery of the body. The public prosecutor ordered a forensic autopsy, and the body was transported to our institute. According to our protocol, a native PMCT of the body was performed by a forensic radiographer 15.78 h after discovery, using the aforementioned acquisition parameters (Table 1). The images were interpreted by a board-certified radiologist with many years of experience in forensic imaging. The images revealed a linear delimitation between the anterior and posterior regions of the brain, along with a density in the anterior part, compatible with an advanced stage of decomposition. Images also showed fresh intracranial hemorrhages (e.g. left frontal lobe) (Figs. 2a and 2b). The subsequent autopsy was performed 40.28 h after the discovery of the body, by a team of physicians (one board-certified forensic pathologist and one resident in training). It revealed traumatic injuries such as fresh subdural and subarachnoid hemorrhages, fresh intraparenchymal brain hematomas, fresh minor traumatic injuries (contusions, abrasions) over the head trunk and limbs, along with some skin and subcutaneous defects compatible with postmortem predation (face, back and left hand) (Fig. 3). The autopsy also showed signs of hypothermia (rare Wischnewski spots, reddened synovial fluid of the knee joints). A neuropathologist performed a neuropathological examination of the brain after six weeks of fixation. We then retrospectively compared areas of different densities observed on CT imaging with the neuropathological examination (left frontal lobe, Figs. 4a and 4b and right hippocampus, Figs. 5a and 5b). Apart from some pericellular vacuolization considered as artifacts of fixation, we were not able to identify any macroscopic or microscopic pathological finding correlating with the different areas of CT density. Moreover, immunohistochemistry CD68 staining performed to assess macrophages and microglia response to ischemic insult did not reveal any expression difference between samples collected from areas of different densities (left frontal lobe, Fig. 6a and right hippocampus, Fig. 6b). The amount of CD68 + macrophages and microglial cells was within the normal range. Toxicology studies revealed the presence of high levels of ethanol in femoral blood and urine samples, along with antidepressants (venlafaxine, trazodone) and benzodiazepines (alprazolam, oxazepam) within the therapeutic range. The cause of death was attributed to a traumatic brain injury in the context of cold exposure.

Case 2

The second case displayed a 77-year-old male, who was found dead on the bottom of a cliff, near where his car has been found. Temperatures recorded then in the area approached 9 °C (48.2°F). The body was transported to our facilities before the forensic autopsy requested by the public prosecutor, without on-site retrieval of the body by a forensic pathologist. However, a technical malfunction occurred in the cooling cell during the storage of the corpse and the body was exposed to a temperature of approximately 0 °C (32°F) for about six hours. A native postmortem CT scan of the body was performed 23.28 h after discovery, using the same acquisition parameters as the first case. The images were interpreted by the same radiologist as the first case. They revealed a grossly circular zone of hypodensity across the periphery of the brain, with a centro-peripheral and right-to-left gradient (Figs. 7a and 7b). The autopsy was performed 43.58 h after discovery by a different team of physicians. It showed a severe polytrauma with fresh blunt injuries and hemorrhagic infiltrations of the scalp, fresh subarachnoid/petechial/intraventricular hemorrhages in the brain, fresh epidural, and intramedullary hemorrhages, along with fractures of the spine (cervical, thoracolumbar), the ribs (with pulmonary contusions) and of some limb bones (right fibula, both scapulae, left clavicle). A neuropathological examination of the brain was also performed by a neuropathologist after six weeks of fixation, and we also retrospectively compared histological samples originating from areas of the different densities found on imaging. No major differences were observed in those specific regions (left

Table 1
Acquisition parameters for postmortem brain CT sequences (GE Discovery CT750 HD).

Parameter				Axial mode acquisition
KV				120
mA				300
Tube rotation				1 " (per second)
	Slice Thickness	Interval (contigous)	Algorithm	Adaptative Statistical Iterative Reconstruction (ASIR)
Acquisition reconstruction	5 mm	5 mm	Standard	AR70 (70%)
Second reconstruction	1,25 mm	1,25 mm	Standard	AR70 (70%)
Third reconstruction	1,25 mm	1,25 mm	Bone+	AR20 (20%)

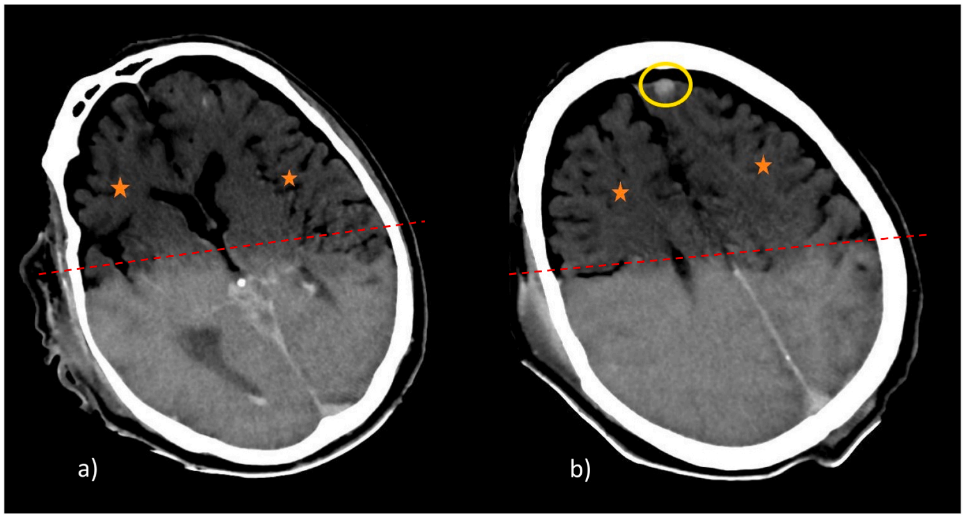

Fig. 2. Case 1: Native postmortem CT-images showing in an axial view the brain at two different levels (a) more distal than b)) with a linear delimitation between the anterior and posterior regions of the brain (dashed red line), with a hypodensity compatible with an increased state of decomposition in the anterior region (orange stars). Fresh intraparenchymal hemorrhages (e.g., left frontal lobe) were also seen (yellow circle, b).

Fig. 3. Case 1: General view of the upper part of the body at external examination.

frontal lobe, Figs. 8a and 8b), and right hippocampus Figs. 9a and 9b). The toxicological analysis only showed traces of ethanol and caffeine metabolites in peripheral blood. The cause of death was deemed to be severe polytrauma, mainly craniocerebral and cervical.

To summarize, the complete neuropathological examination of both cases was not able to identify any pathological finding correlating with the density differences observed on imaging. Moreover, no sign of a different state of decomposition between the two regions of different densities was observed.

Discussion

In the living, low density observed on brain CT images generally transcripts either edema or necrosis [12,13]. Postmortem, a decrease in CT attenuation may also indicate cerebral autolysis, as a reflection of the decomposition process [1]. Moreover, even after a short postmortem interval, it is common to observe a loss of differentiation between gray and white matter as a known postmortem phenomenon [1]. However, in general, the density of different substances changes with temperature [14]. Freezing has been reported to lead to a decreased density in brain parenchyma [15,16]. Normal brain parenchyma is supposed to be denser than liquid water, which is in turn denser than ice [17]. Water density is about 1 g/cm^3 and remains constant between 0 °C (32°F) and normal body temperature. However, ice's density is about 0.9 g/cm^3 so

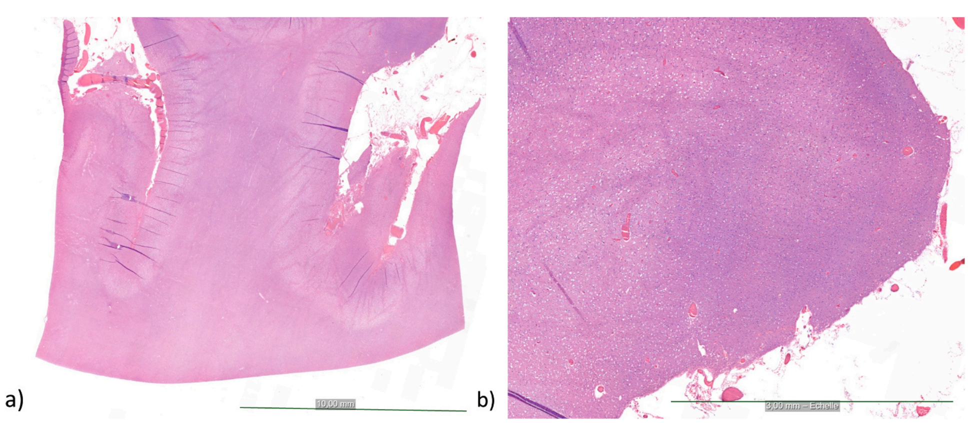

Fig. 4. Case 1: Low-power (a) and high-power (b) magnification of the left frontal lobe on hematoxylin and eosin (HE) staining showing peri-cellular vacuolization. Echelle = Scale.

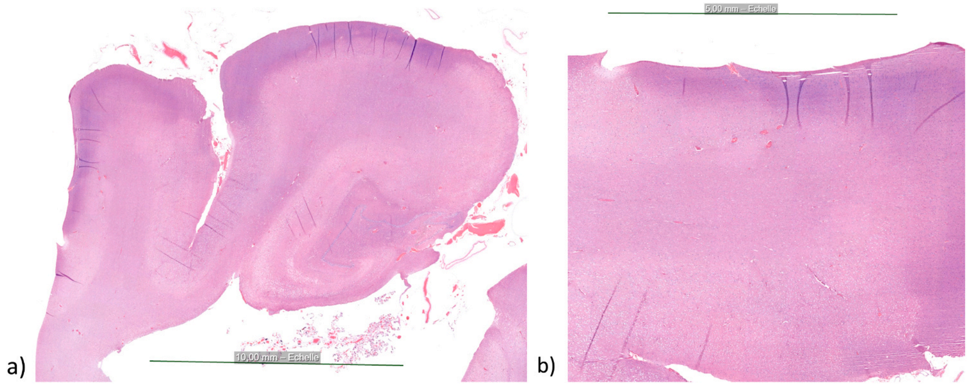

Fig. 5. Case 1: Low-power (a) and high-power (b) magnification of the right hippocampus on hematoxylin and eosin (HE) staining showing peri-cellular vacuolization. Echelle = Scale.

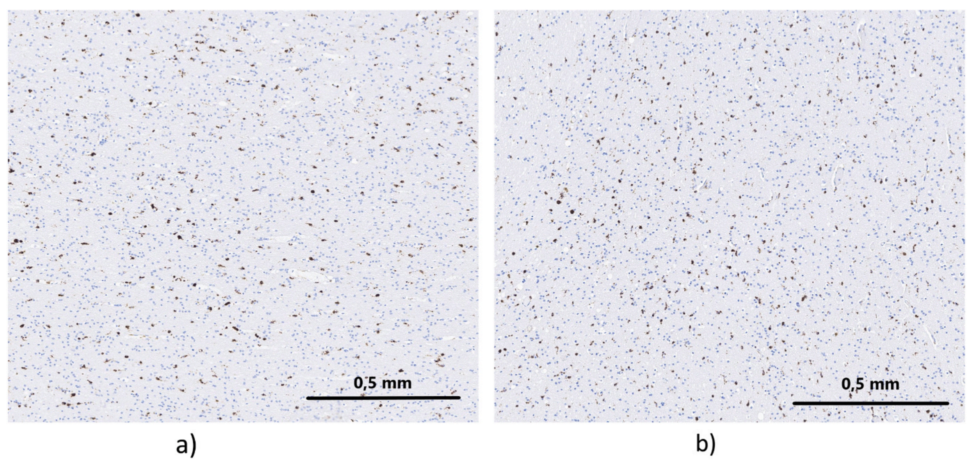

Fig. 6. Case 1: Infiltrates of CD68 + macrophages and microglial cells in the left frontal lobe (a) and the right hippocampus (b), within normal range, highlighted by the anti-CD68 + monoclonal antibody.

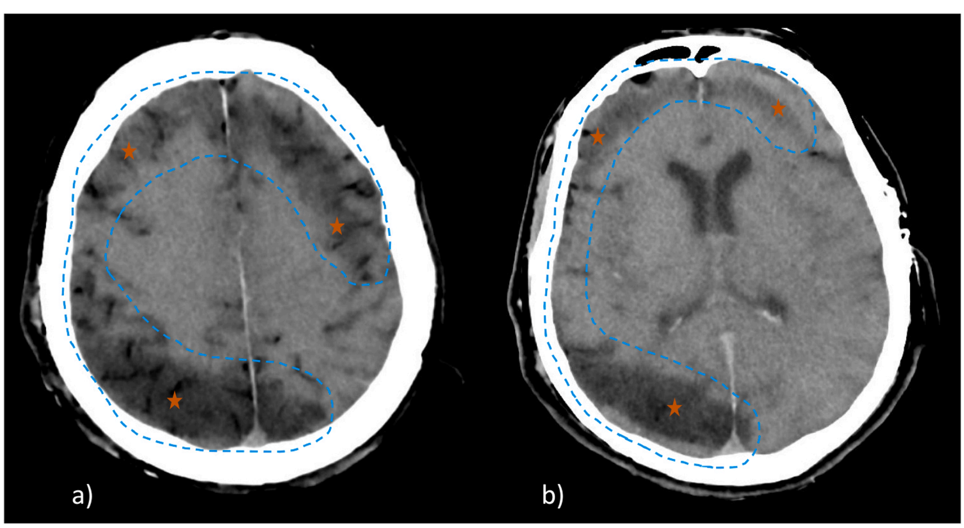

Fig. 7. Case 2: Native postmortem CT-images showing in an axial view the brain at two different levels, (a) more proximal than b)), with a grossly circular zone (dashed blue freehand form) of hypodensity (orange stars) across the periphery of the brain.

a difference in visible attenuation is to be expected in the frozen state compared with temperatures above 0 °C (32°F) [14]. The two cases presented illustrate the different processes through which the cold might affect brain tissue, especially the density observed on CT images. The first body was found dead laying in a supine position in the snow, with a hypodensity in the anterior part of the brain on imaging, suggesting that the anterior part of his body was submitted to colder temperatures than the posterior part. Alternatively, the second body was submitted to cold

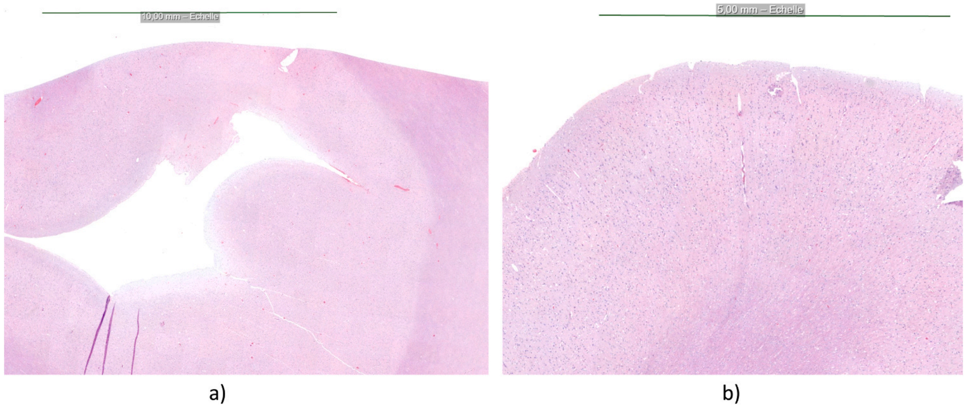

Fig. 8. Case 2: Low-power (a) and high-power (b) magnification of the left frontal lobe on hematoxylin and eosin (HE) staining. Echelle = Scale.

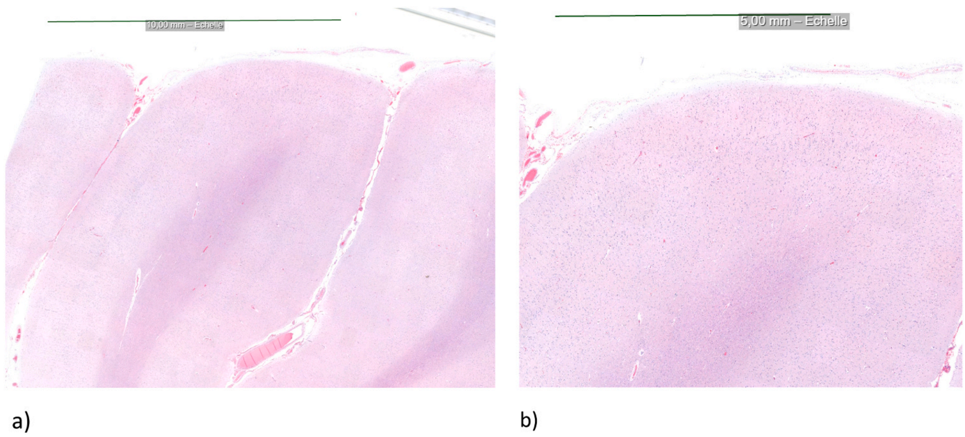

Fig. 9. Case 2: Low-power (a) and high-power (b) magnification of the right hippocampus on hematoxylin and eosin (HE) staining. Echelle = Scale.

temperatures as he was laying supine in a cooling cell and displayed a hypodensity in the periphery of the brain, suggesting that the cold affected the outer layer of the brain before its core. It is worth mentioning that the disposition of the hyperdense area in the brain depicted in the first case (posterior part of the brain) could open a differential including hypostasis (livor mortis) due to the supine position. However, this hypothesis implies that such changes should also be observed in other corpses, frequently discovered in the supine position. Moreover, the disposition of the hyperdense areas in the second case (in the center of the brain) further disputes that hypothesis.

We then began to wonder about the possible explanation of this phenomenon, which could in turn represent a potential pitfall in our assessment of forensic cases. We searched in the forensic literature and only found a few articles regarding this topic. They mainly targeted experimental postmortem freezing of the brain in already altered corpses, to try to hinder further decomposition [16–20]. Hyodoh et al. published experiments carried out on extracted putrefied pig brains with CT imaging and histological sampling. The authors interestingly reported a homogeneous low density of the brain parenchyma after more than 14 h of freezing and no freezing effect on histological staining was mentioned [19]. Sugimoto et al. observed lower density regions on postmortem brain CT, performed after artificial freezing by applicating dry ice near the cephalic area of two putrefied bodies and an extracted pig brain tissue [16]. Kawasumi et al. reported two cases of naturally and partially frozen fresh corpses displaying hypodense areas on brain postmortem CT imaging, however, no histological analysis was performed [20].

We also came across experiments carried out on porcine brains with controlled freezing and subsequent thawing, along with serial imaging using PMCT and postmortem magnetic resonance imaging (PMMRI), and histological sampling [21]. However, in this study, Bolliger et al. focused on thawing artifacts and interestingly did not report changes in the density or signal of the brain parenchyma on imaging.

We also searched the clinical literature for a similar phenomenon, especially in studies concerning CT findings in patients treated by therapeutic hypothermia (generally up to 32–34 °C (89.6–93.2°F)) after resuscitation following cardiac arrest [22]. When low-density areas were described, they respected the anatomical topography expected in hypoxic/ischemic injuries, without obvious relation to cold exposure. The absence of similar findings as ours in a clinical setting is not a surprise, given the higher body temperature than in our presented cases. However, some papers about stereotactic cryoablation of intracerebral tumors guided with intra-operative computed tomography showed some interestingly similar traits. Indeed, the "ice-ball formation" expected around the probe (after freezing to about −40 °C(−40°F)) was seen on CT images as a "black void" (meaning a low-density circular area surrounding the probe) [23,24].

Forensic pathologists dealing with corpses retrieved in low/freezing temperatures should be aware of the possible influence of environmental factors on postmortem images and the possible occurrence of such a peculiar finding. To avoid misinterpretation in such cases, correlation with a thorough neuropathological examination is advisable.

PMMRI offers higher performances in the assessment of organ parenchyma, especially the brain and soft tissues, and can detect some pathological conditions that are not easily identifiable with PMCT (e.g. cervical spine and medullary injuries, ischemic myocardium, inflammatory and infectious diseases of the brain, neurodegenerative diseases etc.). However, it remains less accessible in most centers of legal medicine and MR signal intensity is known to be affected by low temperatures [14,25]. However, in our institute, we have been able to get good-quality images on PMMRI concerning most standard radiological clinical sequences even with temperatures as low as 4 °C (39.2°F), so cold temperatures should not be such a limiting factor.

This phenomenon needs further experimental investigations, with controlled temperatures settings in a predefined time sequence, and well-documented CT images (with Hounsfield unit measurements) ideally correlated with the adequate MRI sequences (T1, T2) with or without mapping sequences (measurement of the T1 and T2 relaxation times of the brain tissues) and targeted histological sampling in areas of the brain that might exhibit radiological visible changes attributable to low temperatures.

Conclusion

There seems to be a direct correlation between the low temperatures and the reflected density of the brain parenchyma on CT imaging. This should be known for adequate interpretation of PMCT. Further research is essential to better understand that phenomenon, as neuropathological analysis did not show any significant difference. The addition of the MRI to the standard postmortem CT-imaging protocol in such cases could allow a better analysis of the brain parenchyma, despite the inherent temperature variability.

Declaration of Competing Interest

We have no conflicts of interest to disclose.

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