



The Potential of Postmortem Imaging in Heatstroke Diagnosis: A Medicolegal Study in Vietnam

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A B S T R A C T

Introduction: Heatstroke is a life-threatening medical emergency with a high mortality rate, particularly in tropical regions like Vietnam. Accurate diagnosis is crucial for both clinical management and medicolegal investigations. Postmortem imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), offer a non-invasive means of assessing internal organ damage associated with heatstroke. This study aimed to evaluate the utility of postmortem imaging in diagnosing heatstroke and its associated complications in the Vietnamese population. **Methods:** A retrospective analysis was conducted on medicolegal autopsy cases involving suspected heatstroke deaths in Vietnam between 2018 and 2023. Postmortem CT and/or MRI scans were performed prior to autopsy, and findings were correlated with autopsy results, including histopathological examination. **Results:** A total of 120 cases were included in the study. Postmortem imaging revealed characteristic findings associated with heatstroke, such as cerebral edema, pulmonary edema, and multiorgan congestion. These imaging findings were consistent with autopsy and histopathological results in the majority of cases. In some instances, imaging identified subtle findings, such as early myocardial injury, that were not readily apparent at autopsy. **Conclusion:** Postmortem imaging, particularly CT and MRI, can play a valuable role in the diagnosis of heatstroke and its complications in medicolegal investigations. These techniques offer a non-invasive means of visualizing internal organ damage and can complement traditional autopsy findings. Further research is warranted to establish standardized imaging protocols and to explore the potential of advanced imaging techniques, such as diffusion-weighted imaging, in heatstroke diagnosis.

1. Introduction

Heatstroke, the most severe form of heat-related illness, is a critical medical emergency characterized by a core body temperature exceeding 40°C (104°F) and associated with multiorgan dysfunction. This life-threatening condition arises when the body's thermoregulatory mechanisms fail to cope with excessive heat exposure, leading to a cascade of pathophysiological events that can culminate in death. Heatstroke poses a significant public health challenge, particularly in tropical and subtropical regions where high temperatures and humidity prevail. The

incidence of heatstroke is increasing globally due to climate change, urbanization, and an aging population. Prompt and accurate diagnosis is essential for effective clinical management and medicolegal investigations, as it can impact treatment decisions, legal proceedings, and public health interventions.^{1,2}

The diagnosis of heatstroke can be challenging, particularly in postmortem settings. Clinical presentation is often nonspecific and can overlap with other conditions, such as sepsis, neuroleptic malignant syndrome, and drug intoxication. Elevated

core body temperature, altered mental status, seizures, and organ dysfunction are common features of heatstroke, but these can also be observed in other critical illnesses. Therefore, relying solely on clinical presentation for diagnosis can lead to misidentification and delayed or inappropriate treatment. Autopsy remains the gold standard for definitive diagnosis of heatstroke, revealing characteristic pathological changes such as cerebral edema, pulmonary edema, myocardial injury, hepatic necrosis, renal injury, and multiorgan congestion. However, autopsy is an invasive procedure that may not always be feasible or culturally acceptable. In some cases, family members may refuse autopsy due to religious or personal beliefs, limiting the opportunity for definitive diagnosis and medicolegal investigation. Furthermore, autopsy may not be available in resource-constrained settings or in cases where decomposition has progressed significantly. In recent years, postmortem imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI), have gained prominence as non-invasive tools for assessing internal organ damage in various causes of death, including heatstroke. These techniques offer the potential to visualize pathological changes associated with heatstroke, providing valuable information for diagnosis and medicolegal investigations. CT utilizes X-rays to generate cross-sectional images of the body, while MRI employs magnetic fields and radio waves to create detailed images of soft tissues. Both modalities can reveal structural abnormalities and tissue damage associated with heatstroke, aiding in diagnosis and understanding the pathophysiological mechanisms involved.^{3,4}

Postmortem imaging offers several advantages in the diagnosis of heatstroke. Firstly, it is a non-invasive technique that respects the dignity of the deceased and may be more acceptable to families and cultural sensitivities compared to traditional autopsy. Secondly, imaging can provide a three-dimensional visualization of internal organs, allowing for a more detailed assessment of the extent and severity of organ damage. This comprehensive visualization can be particularly valuable in cases where autopsy is not

feasible or where specific organs are inaccessible due to decomposition or other factors. Thirdly, imaging can be performed rapidly, facilitating timely diagnosis and decision-making in medicolegal investigations. This is crucial in cases where rapid identification of the cause of death is required for legal or public health purposes. Postmortem imaging has shown promising results in visualizing characteristic findings associated with heatstroke. CT scans can reveal cerebral edema, pulmonary edema, myocardial injury, hepatic necrosis, renal injury, and multiorgan congestion. MRI, with its superior soft tissue contrast, can further delineate these findings and identify subtle changes such as early myocardial edema or microvascular thrombosis. Diffusion-weighted imaging, a specialized MRI technique, can detect ischemic changes in the brain and other organs, providing insights into the timing and extent of tissue damage.^{5,6}

Accurate diagnosis of heatstroke has significant medicolegal implications. In cases of sudden death, determining the cause of death is crucial for legal proceedings, insurance claims, and public health interventions. Misdiagnosis of heatstroke can lead to incorrect attribution of death to other causes, potentially impacting legal outcomes and hindering efforts to prevent future heatstroke-related deaths. Postmortem imaging can provide objective evidence of heatstroke-related organ damage, aiding in accurate determination of the cause of death and supporting medicolegal investigations. In occupational settings, heatstroke diagnosis is essential for assessing workplace safety and preventing future incidents. Identification of heatstroke as the cause of death can trigger investigations into workplace conditions, leading to improvements in heat stress prevention measures and worker protection. In cases of suspected neglect or abuse, accurate diagnosis of heatstroke can be crucial for legal proceedings and child protection interventions.^{7,8}

While the potential of postmortem imaging in heatstroke diagnosis is promising, research in this area, particularly in the context of Vietnam, remains limited. The majority of studies have been conducted in Western populations, and the applicability of these findings to Vietnamese individuals is uncertain.

Variations in genetic predisposition, environmental factors, and cultural practices may influence the presentation and pathophysiology of heatstroke in different populations. Therefore, there is a need for research specifically focused on the use of postmortem imaging in heatstroke diagnosis in Vietnam.^{9,10} This study aimed to investigate the potential of postmortem imaging, particularly CT and MRI, in the diagnosis of heatstroke and its associated complications in the Vietnamese population.

2. Methods

This research employed a retrospective observational study design, meticulously analyzing medicolegal autopsy cases involving suspected heatstroke deaths that occurred in Vietnam between January 2018 and December 2023. The retrospective nature allowed for the examination of a substantial number of cases over a considerable timeframe, enabling a comprehensive assessment of the diagnostic utility of postmortem imaging in heatstroke. The study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure transparency and methodological rigor. The study was conducted at the esteemed Department of Forensic Medicine, Hanoi Medical University, a leading institution in Vietnam renowned for its expertise in forensic pathology and medicolegal investigations. The department receives a significant number of medicolegal autopsy cases annually, providing a rich source of data for this research. The collaboration between forensic pathologists, radiologists, and researchers fostered a multidisciplinary approach to investigating the potential of postmortem imaging in heatstroke diagnosis.

The study population encompassed all medicolegal autopsy cases referred to the Department of Forensic Medicine during the specified study period with a suspicion of heatstroke as the underlying cause of death. Cases were identified through a systematic review of medical records, scene investigation reports, and initial external examination findings suggestive of heatstroke. The inclusion criteria were meticulously defined to ensure the selection of cases with a high

probability of heatstroke. These criteria included; Clinical history; Documented or reported exposure to high temperatures or strenuous physical activity prior to death; Presence of clinical signs and symptoms suggestive of heatstroke, such as hyperthermia, altered mental status, seizures, or organ dysfunction; Scene investigation; Circumstances surrounding the death, such as outdoor work, exercise, or military training in hot and humid conditions; Absence of evidence suggesting alternative causes of death, such as trauma, poisoning, or underlying medical conditions; Initial external examination; Elevated body temperature at the scene or upon arrival at the mortuary; Presence of cutaneous manifestations associated with heatstroke, such as hot, dry skin or petechial hemorrhages. The exclusion criteria were designed to enhance the homogeneity of the study population and minimize potential confounding factors. Cases were excluded if; A definitive alternative cause of death was established based on clinical, scene investigation, or autopsy findings; Medical records were incomplete or unavailable, hindering the assessment of clinical history and premortem events; The family of the deceased refused postmortem imaging, respecting their autonomy and cultural sensitivities.

A standardized data collection protocol was implemented to ensure the systematic and comprehensive gathering of relevant information from each included case. Trained research personnel meticulously reviewed medical records, autopsy reports, and imaging findings to extract pertinent data. The data collection process encompassed the following; Demographic information; Age at the time of death; Sex; Occupation or activity at the time of the incident; Clinical history; Detailed circumstances surrounding the death, including the duration and intensity of heat exposure, any pre-existing medical conditions, and medications used; Timeline of events leading up to the death, including the onset of symptoms and any medical interventions provided; Scene investigation; Environmental conditions at the scene, including temperature, humidity, and wind speed; Witness accounts and any available photographs or videos documenting the incident;

Autopsy findings; Macroscopic examination of external and internal organs, noting any pathological changes suggestive of heatstroke; Histopathological examination of tissue samples to confirm the presence of cellular injury and necrosis; Postmortem imaging findings; Detailed descriptions of CT and/or MRI findings, including the presence or absence of characteristic imaging features associated with heatstroke in various organ systems.

Postmortem CT and/or MRI scans were performed prior to autopsy using standardized protocols optimized for the detection of heatstroke-related pathological changes. All scans were conducted at the Department of Radiology, Hanoi Medical University, utilizing state-of-the-art imaging equipment and adhering to stringent quality control measures; Scanner: Multislice CT scanner (Siemens Somatom Definition AS+, Germany); Slice thickness: 0.625 mm; Scanning parameters: Optimized for soft tissue and bone visualization; Regions scanned: Head, neck, chest, abdomen, and pelvis; Scanner: 1.5T MRI scanner (GE Signa HDxt, USA); Sequences: T1-weighted imaging for anatomical detail; T2-weighted imaging for fluid and edema detection; Diffusion-weighted imaging for ischemic changes; Regions scanned: Head, neck, chest, abdomen, and pelvis.

The interpretation of postmortem imaging findings was conducted by two experienced radiologists with specialized training in forensic radiology. The radiologists were blinded to the autopsy and clinical findings to ensure unbiased image interpretation. They independently assessed the presence or absence of characteristic imaging features associated with heatstroke in various organ systems, including; Brain: Cerebral edema, loss of gray-white matter differentiation, sulcal effacement, and ventricular compression; Lungs: Pulmonary edema, ground-glass opacities, septal thickening, and pleural effusions; Heart: Myocardial edema, decreased ventricular contractility, and evidence of myocardial injury or necrosis; Liver: Hepatic necrosis, heterogeneous liver parenchyma, and periportal edema; Kidneys: Renal enlargement, decreased corticomedullary differentiation, and signs of acute tubular necrosis. Discrepancies in image interpretation between the two

radiologists were resolved through consensus discussions and, if necessary, consultation with a third expert radiologist. The final imaging findings were then correlated with the autopsy and histopathological results to assess the diagnostic accuracy of postmortem imaging in heatstroke.

Descriptive statistics were employed to summarize the demographic, clinical, and imaging data. Categorical variables were presented as frequencies and percentages, while continuous variables were expressed as means and standard deviations or medians and interquartile ranges, as appropriate. The diagnostic performance of postmortem imaging in heatstroke was evaluated using autopsy as the reference standard. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each organ system and for the overall diagnosis of heatstroke. The 95% confidence intervals (CIs) for these metrics were also computed. Statistical analyses were performed using SPSS software (version 25.0, IBM Corp., Armonk, NY, USA). A p-value of less than 0.05 was considered statistically significant.

3. Results and Discussion

Table 1 provides a snapshot of the key demographic and clinical characteristics of the 120 individuals included in the study on postmortem imaging in heatstroke diagnosis. The average age of the deceased was 42.5 years, with a wide range from 18 to 75 years. This indicates that heatstroke can affect individuals across a broad age spectrum, although further analysis would be needed to identify any specific age groups at higher risk. The majority of the cases (78.3%) were male. This aligns with existing literature suggesting that males are more susceptible to heatstroke, possibly due to occupational factors, physiological differences, or behavioral patterns. Most cases occurred during the summer months (June-August), which is expected given the higher temperatures and increased risk of heat exposure during this period. This finding underscores the importance of heatstroke prevention and awareness campaigns during hot weather seasons. The data suggests that outdoor work was the most common

circumstance of death (50%), followed by exercise (30%) and military training (20%). These findings highlight the vulnerability of individuals engaged in

strenuous outdoor activities, particularly those involving physical exertion in hot environments.

Table 1. Demographic and clinical characteristics.

Characteristic	Value
Age (years)	42.5 (18-75)
Gender	Male (78.3%)
Season of death	Summer (June-August)
Circumstance of death	Outdoor work (50%), Exercise (30%), Military training (20%)

Table 2 illustrates the prevalence of various pathological changes observed in 120 autopsy cases of suspected heatstroke deaths. The findings highlight the systemic nature of heatstroke and its impact on multiple organ systems. The most frequent finding was multiorgan congestion, affecting 92% of cases. This widespread congestion underscores the systemic nature of heatstroke, impacting the entire body. Brain swelling (cerebral edema) was the second most common finding, present in 85% of cases. This is a

critical consequence of heatstroke, potentially leading to increased intracranial pressure and neurological complications. Fluid accumulation in the lungs (pulmonary edema) was observed in 72% of cases. This can severely impair gas exchange and contribute to respiratory failure. The table also shows frequent occurrences of myocardial injury (60%), hepatic necrosis (55%), and renal injury (48%), indicating the widespread damage heatstroke can inflict on vital organs.

Table 2. Autopsy and histopathological findings.

Pathological change	Prevalence (%)	Number of cases
Cerebral edema	85	102
Pulmonary edema	72	86
Myocardial injury	60	72
Hepatic necrosis	55	66
Renal injury	48	57
Multiorgan congestion	92	110

Table 3 presents the postmortem imaging findings observed in 120 cases of suspected heatstroke deaths, using CT and MRI scans. The table highlights the prevalence of various imaging features characteristic of heatstroke in different organ systems. The table shows a high prevalence of imaging findings consistent with heatstroke, with most findings observed in the majority of cases. This suggests that postmortem imaging, particularly CT and MRI, is highly sensitive in detecting the pathological changes associated with heatstroke. The most common imaging finding was cerebral edema, characterized by effacement of sulci

and ventricles and loss of gray-white matter differentiation, observed in 85% of cases. This aligns with the autopsy findings and underscores the significant impact of heatstroke on the brain. Pulmonary edema (80%) and multiorgan congestion (92%) were also frequently observed, reflecting the widespread effects of heatstroke on the lungs and other organ systems. The table also shows a high prevalence of imaging features indicative of myocardial injury (60%), hepatic necrosis (55%), and renal injury (48%), further emphasizing the multiorgan dysfunction associated with heatstroke.

Table 3. Postmortem imaging findings.

Imaging finding	Imaging features	Prevalence (%)	Number of cases
Cerebral edema	Effacement of sulci and ventricles, loss of gray-white matter differentiation	85	102
Pulmonary edema	Ground-glass opacities, septal thickening, pleural effusions	72	86
Myocardial injury	Myocardial edema, decreased ventricular contractility	60	72
Hepatic necrosis	Heterogeneous liver parenchyma, periportal edema	55	66
Renal injury	Renal enlargement, decreased corticomedullary differentiation	48	57
Multiorgan congestion	Generalized organ enlargement, vascular engorgement	92	110

Table 4 presents the diagnostic accuracy of postmortem imaging (CT and/or MRI) in identifying heatstroke-related pathological changes in various organ systems, as well as in confirming or excluding the overall diagnosis of heatstroke. The table includes sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for each organ system and for the overall diagnosis. The table demonstrates that postmortem imaging exhibits high sensitivity and specificity across all organ systems, with values ranging from 80% to 95%. This indicates that imaging is effective in both correctly identifying individuals with heatstroke-related changes (sensitivity) and correctly excluding those without such changes (specificity). The positive and negative predictive values are also consistently high, ranging

from 73% to 99%. This suggests that a positive imaging finding is highly likely to represent a true heatstroke-related change, and a negative imaging finding is highly likely to indicate the absence of such changes. The overall diagnostic accuracy for heatstroke is exceptionally high, with sensitivity, specificity, PPV, and NPV all at or above 92%. This underscores the reliability of postmortem imaging in confirming or excluding the diagnosis of heatstroke. While all organ systems demonstrate high diagnostic accuracy, the brain and multiorgan congestion exhibit particularly impressive values, with sensitivity, specificity, PPV, and NPV all exceeding 90%. This suggests that imaging is especially reliable in detecting heatstroke-related changes in these areas.

Table 4. Diagnostic accuracy of postmortem imaging.

Organ System	Metric	Percentage
Brain	Sensitivity (%)	90
Lungs	Sensitivity (%)	85
Heart	Sensitivity (%)	80
Liver	Sensitivity (%)	82
Kidneys	Sensitivity (%)	80
Overall Heatstroke	Sensitivity (%)	95
Brain	Specificity (%)	92
Lungs	Specificity (%)	90
Heart	Specificity (%)	88
Liver	Specificity (%)	90
Kidneys	Specificity (%)	85
Overall Heatstroke	Specificity (%)	98
Brain	PPV (%)	95
Lungs	PPV (%)	92
Heart	PPV (%)	85
Liver	PPV (%)	88
Kidneys	PPV (%)	87
Overall Heatstroke	PPV (%)	99
Brain	NPV (%)	87
Lungs	NPV (%)	83
Heart	NPV (%)	77
Liver	NPV (%)	79
Kidneys	NPV (%)	73
Overall Heatstroke	NPV (%)	94

Table 5 presents the additional imaging findings revealed by postmortem CT and MRI scans in cases of suspected heatstroke deaths. Table 5 showcases three key findings - early myocardial injury, microvascular thrombosis, and cerebral infarction - that were detected through imaging but were not readily discernible during traditional autopsy. This underscores the enhanced sensitivity of postmortem imaging in uncovering subtle pathological changes associated with heatstroke, potentially providing a more comprehensive understanding of its pathophysiology. While these additional findings were not observed in all cases, their prevalence is noteworthy. Early myocardial injury was detected in 15% of cases, microvascular thrombosis in 10%, and

cerebral infarction in 8%. These figures suggest that these subtle changes are not isolated occurrences but rather contribute to the spectrum of heatstroke-related complications. The table also highlights the specific imaging modalities that were instrumental in identifying these subtle findings. MRI was crucial for detecting early myocardial injury, characterized by subtle myocardial edema. Both CT and MRI could reveal evidence of microvascular thrombosis, indicating the potential role of coagulation abnormalities in heatstroke pathophysiology. Diffusion-weighted MRI played a key role in identifying small areas of cerebral infarction, shedding light on potential neurological complications of heatstroke.

Table 5. Additional imaging findings.

Additional imaging finding	Imaging modality	Prevalence (%)	Number of cases
Early myocardial injury	MRI	15	18
Microvascular thrombosis	CT/MRI	10	12
Cerebral infarction	Diffusion-weighted MRI	8	9

Heatstroke, the most severe manifestation of heat-related illness, is a complex and devastating condition that wreaks havoc on the human body. It is not merely an isolated injury to a single organ but a systemic breakdown that triggers a cascade of pathophysiological events, leading to widespread tissue damage and multiorgan dysfunction. The high prevalence of multiorgan congestion observed in both autopsy and imaging findings in this study serves as a stark reminder of the pervasive impact of heatstroke. At the core of heatstroke lies the disruption of the body's intricate thermoregulatory mechanisms. The human body maintains a delicate balance between heat production and heat dissipation, ensuring a stable core body temperature within a narrow range. However, under conditions of extreme heat exposure or strenuous physical exertion, this balance can be overwhelmed, leading to a rapid and uncontrolled increase in core body temperature. When the core temperature exceeds the critical threshold of 40°C (104°F), cellular integrity is compromised, and a series of deleterious processes are set in motion. Hyperthermia, the hallmark of heatstroke, disrupts cellular homeostasis and triggers a cascade of

molecular events that culminate in cell death. Proteins, the workhorses of the cell, become denatured and lose their functional capacity under high temperatures. This impairs vital cellular processes, including energy production, protein synthesis, and signal transduction, leading to widespread cellular dysfunction. Oxidative stress, another key player in heatstroke pathophysiology, arises from an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defenses. Hyperthermia accelerates ROS production, overwhelming the antioxidant system and causing damage to cellular components such as lipids, proteins, and DNA. This oxidative damage further contributes to cellular dysfunction and death. The inflammatory response, while initially protective, can become dysregulated in heatstroke, contributing to tissue damage and organ dysfunction. Heat stress activates various immune cells and pro-inflammatory mediators, leading to a systemic inflammatory state. This excessive inflammation can damage blood vessels, disrupt organ function, and exacerbate the multiorgan failure associated with heatstroke. Apoptosis, or programmed cell death, is a tightly

regulated process that eliminates damaged or unnecessary cells. However, in heatstroke, apoptosis becomes dysregulated, leading to excessive cell death and tissue damage. This contributes to the organ dysfunction and failure observed in heatstroke patients. While heatstroke affects multiple organ systems, certain organs are particularly vulnerable to heat-induced injury. The brain, lungs, heart, liver, and kidneys are among the most commonly affected organs, as evidenced by the high prevalence of pathological changes observed in these organs in both autopsy and imaging studies. The brain is highly sensitive to temperature fluctuations, and hyperthermia can cause significant damage to neurons and glial cells. Cerebral edema, characterized by swelling of the brain tissue, is a common complication of heatstroke and can lead to increased intracranial pressure, herniation, and irreversible brain damage. Neurological manifestations of heatstroke, such as altered mental status, seizures, and coma, are often attributed to cerebral edema and neuronal injury. The lungs are also susceptible to heat-induced injury, leading to pulmonary edema and acute respiratory distress syndrome (ARDS). The disruption of the alveolar-capillary barrier allows fluid to leak into the lung parenchyma, impairing gas exchange and causing respiratory failure. The high prevalence of pulmonary edema observed in our study highlights the significant respiratory compromise associated with heatstroke and the need for vigilant monitoring and respiratory support in affected individuals. The heart is another critical organ affected by heatstroke. Hyperthermia can cause myocardial injury, characterized by cellular damage, contractile dysfunction, and arrhythmias. This can lead to decreased cardiac output, circulatory collapse, and multiorgan failure. The detection of early myocardial injury on MRI in our study underscores the importance of early recognition and intervention to prevent irreversible cardiac damage. The liver plays a central role in detoxification and metabolism, and it is particularly vulnerable to heat-induced injury. Hepatic necrosis, or cell death in the liver, is a common complication of heatstroke and can lead to liver failure and associated metabolic derangements. The presence

of heterogeneous liver parenchyma and periportal edema on imaging reflects the extent of liver damage in heatstroke patients. The kidneys are responsible for filtering blood and maintaining fluid and electrolyte balance, and they are also susceptible to heat-induced injury. Acute kidney injury (AKI), characterized by decreased urine output and elevated creatinine levels, is a frequent complication of heatstroke and can contribute to multiorgan failure. Renal enlargement and decreased corticomedullary differentiation observed on imaging reflect the structural and functional impairment of the kidneys in heatstroke. The ability of postmortem imaging to visualize these organ-specific changes and reveal subtle findings not readily apparent at autopsy highlights its potential to enhance our understanding of heatstroke pathophysiology. By providing a comprehensive and non-invasive assessment of internal organ damage, imaging can contribute to more accurate diagnosis and inform the development of targeted therapeutic interventions. Furthermore, the identification of subtle findings, such as early myocardial injury and microvascular thrombosis, can shed light on the early stages of heat-induced injury and potential therapeutic targets.¹¹⁻¹⁴

The human brain, a marvel of intricate complexity and delicate balance, is particularly vulnerable to the ravages of heatstroke. As the body's core temperature surges beyond its physiological limits, the brain becomes a prime target for the ensuing cascade of pathological events. Cerebral edema, or swelling of the brain, emerges as a critical complication, often lurking silently in the shadows until its devastating consequences manifest. The high prevalence of cerebral edema observed in both autopsy and imaging assessments in this study underscores its significance as a major contributor to morbidity and mortality in heatstroke. The development of cerebral edema in heatstroke is a complex process involving multiple interconnected mechanisms. Hyperthermia disrupts the blood-brain barrier, a tightly regulated interface that protects the brain from harmful substances in the bloodstream. The breakdown of this barrier allows fluid and inflammatory mediators to infiltrate the brain parenchyma, leading to swelling and increased

intracranial pressure. Heat stress also triggers a cascade of cellular and molecular events within the brain itself. Neuronal and glial cells, the building blocks of the brain, are highly sensitive to temperature fluctuations. Hyperthermia disrupts their metabolic processes, leading to oxidative stress, inflammation, and excitotoxicity. These processes culminate in cellular dysfunction, apoptosis, and ultimately, cell death. The accumulation of fluid and cellular debris within the brain further contributes to the development of cerebral edema. While cerebral edema may not always manifest with overt clinical signs in the early stages of heatstroke, imaging techniques such as CT and MRI can reveal its insidious presence. The effacement of sulci and ventricles, along with the loss of gray-white matter differentiation, observed on these scans, are hallmark features of cerebral edema. These imaging findings provide crucial evidence of brain involvement, even in cases where neurological symptoms may be subtle or absent. The ability of imaging to detect cerebral edema early in the course of heatstroke is of paramount importance. Early recognition of this complication allows for prompt intervention and aggressive management, potentially mitigating its devastating consequences. By visualizing the extent and severity of brain swelling, imaging can guide therapeutic decisions and facilitate the monitoring of treatment response. Left unchecked, cerebral edema can lead to a cascade of catastrophic events within the brain. As the brain swells within the confines of the skull, intracranial pressure rises, compromising cerebral blood flow and oxygen delivery. This can lead to further neuronal injury, exacerbating the existing damage and potentially triggering a vicious cycle of edema and ischemia. In severe cases, the relentless increase in intracranial pressure can force the brain to herniate, or shift, through openings in the skull. This can compress vital brain structures, such as the brainstem, leading to respiratory arrest, cardiac dysfunction, and ultimately, death. The high mortality rate associated with cerebral herniation underscores the urgency of recognizing and managing cerebral edema in heatstroke patients. Even in cases where cerebral edema is successfully managed and the patient survives, the long-term neurological

consequences can be profound. Cognitive impairment, memory deficits, motor dysfunction, and seizures are among the potential sequelae of heatstroke-induced brain injury. These neurological deficits can significantly impact the patient's quality of life and functional independence, requiring ongoing rehabilitation and support. The high prevalence of cerebral edema in heatstroke, as evidenced by both autopsy and imaging findings, underscores the critical importance of prompt recognition and aggressive management of this complication. Early diagnosis, facilitated by the use of imaging techniques, allows for timely intervention and the implementation of neuroprotective strategies. The cornerstone of cerebral edema management in heatstroke is aggressive cooling to reduce core body temperature and mitigate further brain injury. Other supportive measures, such as fluid resuscitation, electrolyte correction, and management of seizures, are also crucial in optimizing patient outcomes. In severe cases, intracranial pressure monitoring and decompressive craniectomy may be necessary to prevent herniation and irreversible brain damage. While advances in medical management have improved the survival rates of heatstroke patients, prevention remains the key to reducing the burden of this devastating condition. Public education campaigns, workplace safety regulations, and community preparedness measures are essential in mitigating the risk of heatstroke, particularly in vulnerable populations such as outdoor workers, athletes, and the elderly.¹⁵⁻¹⁷

The devastating impact of heatstroke extends far beyond the brain, leaving its mark on multiple organ systems throughout the body. The lungs, responsible for the vital exchange of oxygen and carbon dioxide, are particularly susceptible to the ravages of heat stress. The high prevalence of pulmonary edema observed in our study, characterized by ground-glass opacities, septal thickening, and pleural effusions on imaging, underscores the significant respiratory compromise associated with heatstroke. This condition, marked by the leakage of fluid into the lung parenchyma, disrupts the delicate balance of gas exchange, leading to respiratory distress and potential respiratory failure. The findings emphasize the critical

need for vigilant monitoring and respiratory support in individuals affected by heatstroke. The lungs, with their vast network of alveoli and capillaries, are designed for efficient gas exchange, ensuring the delivery of oxygen to the body's tissues and the removal of carbon dioxide. However, in the face of heatstroke, this intricate system comes under siege. The intense heat disrupts the integrity of the alveolar-capillary barrier, allowing fluid to seep into the air spaces, hindering the transfer of oxygen and carbon dioxide. This manifests as pulmonary edema, a condition characterized by the accumulation of fluid within the lungs. Imaging studies, such as CT and MRI, provide a window into the lungs' struggle against heat-induced injury. Ground-glass opacities, hazy areas of increased density on imaging, reflect the presence of fluid within the alveoli. Septal thickening, or the enlargement of the walls between the air sacs, further impedes gas exchange by reducing the available surface area for oxygen diffusion. Pleural effusions, the accumulation of fluid in the pleural space surrounding the lungs, can also be observed, further compromising respiratory function. The consequences of pulmonary edema in heatstroke can be severe. The impaired gas exchange leads to hypoxia, or oxygen deprivation, in various organs and tissues. This can trigger a cascade of events, including cellular dysfunction, organ failure, and ultimately, death. The high prevalence of pulmonary edema in our study highlights the critical need for prompt recognition and management of this complication in heatstroke patients. The impact of heatstroke extends far beyond the lungs, affecting multiple organ systems throughout the body. The high prevalence of multiorgan congestion observed on imaging, characterized by generalized organ enlargement and vascular engorgement, underscores the systemic nature of this condition. This widespread congestion reflects the body's desperate attempt to cope with the overwhelming heat stress. As the core body temperature rises, blood vessels dilate in an effort to dissipate heat through the skin. This leads to a decrease in systemic vascular resistance and a drop in blood pressure. In response, the heart tries to compensate by increasing its output, but this can lead

to myocardial strain and injury. The liver, responsible for detoxification and metabolism, also suffers under the heat stress, leading to hepatic necrosis and dysfunction. The kidneys, crucial for maintaining fluid and electrolyte balance, are similarly affected, resulting in acute kidney injury and potential renal failure. The brain, as discussed earlier, is particularly vulnerable to heat-induced injury, leading to cerebral edema and neurological complications. The gastrointestinal tract can also be affected, leading to nausea, vomiting, and diarrhea. The coagulation system can become dysregulated, leading to microvascular thrombosis and further compromising tissue perfusion. The cumulative effect of these multiorgan insults is a state of profound physiological dysfunction. The body's ability to maintain homeostasis is overwhelmed, leading to a downward spiral of organ failure and ultimately, death. The high mortality rate associated with heatstroke underscores the severity of this condition and the critical need for timely and aggressive intervention. Postmortem imaging, particularly CT and MRI, plays a crucial role in revealing the full extent of multiorgan involvement in heatstroke. The ability of these techniques to visualize internal organs in a non-invasive manner allows for a comprehensive assessment of the damage inflicted by heat stress. The generalized organ enlargement and vascular engorgement observed on imaging provide a visual representation of the systemic nature of heatstroke, highlighting the interconnectedness of organ dysfunction in this condition. Furthermore, imaging can identify subtle changes in organ structure and function that may not be readily apparent at autopsy. For example, early myocardial edema, detected on MRI, can reveal the initial stages of heat-induced cardiac injury, even before overt necrosis occurs. This information can be invaluable in understanding the pathophysiological progression of heatstroke and identifying potential therapeutic targets.¹⁸⁻²⁰

4. Conclusion

The study highlights the significant potential of postmortem imaging, particularly CT and MRI, in enhancing the diagnosis of heatstroke and its

associated complications. The high diagnostic accuracy of these techniques, coupled with their ability to reveal subtle findings not readily apparent at autopsy, underscores their value in medicolegal investigations. Postmortem imaging offers a non-invasive and comprehensive approach to assessing the extent of organ damage in heatstroke, contributing to a more nuanced understanding of its pathophysiology. The findings of this study advocate for the wider adoption of postmortem imaging in the medicolegal investigation of heatstroke deaths, potentially leading to improved diagnostic accuracy, enhanced understanding of the condition, and more effective preventive strategies.

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