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Racking the brain: Detection of cerebral edema on postmortem computed tomography compared with forensic autopsy

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ABSTRACT

Purpose: The purpose of this study was to compare postmortem computed tomography with forensic autopsy regarding their diagnostic reliability of differentiating between pre-existing cerebral edema and physiological postmortem brain swelling.

Materials and methods: The study collective included a total of 109 cases ($n = 109/200$, 83 male, 26 female, mean age: 53.2 years) and were retrospectively evaluated for the following parameters (as related to the distinct age groups and causes of death): tonsillar herniation, the width of the outer and inner cerebrospinal fluid spaces and the radiodensity measurements (in Hounsfield Units) of the gray and white matter.

The results were compared with the findings of subsequent autopsies as the gold standard for diagnosing cerebral edema. p-Values <0.05 were considered statistically significant.

Results: Cerebellar edema (despite normal postmortem swelling) can be reliably assessed using postmortem computed tomography and is indicated by narrowed temporal horns and symmetrical herniation of the cerebellar tonsils ($p < 0.001$). There was a significant difference ($p < 0.001$) between intoxication (or asphyxia) and all other causes of death; the former causes demonstrated higher deviations of the attenuation between white and gray matter (>20 Hounsfield Units), and the gray to white matter ratio was >1.58 when leukoencephalopathy was excluded.

Conclusions: Despite normal postmortem changes, generalized brain edema can be differentiated on postmortem computed tomography, and white and gray matter Hounsfield measurements help to determine the cause of death in cases of intoxication or asphyxia. Racking the brain about feasible applications for a precise and reliable brain diagnostic forensic radiology method has just begun.

1. Introduction

Over the last decade, state-of-the-art forensic investigations have established PMCT as a triage tool, a valuable supplement to autopsy and a replacement for autopsy in selected cases [1–3]. However, forensic radiology is a new field and as such offers narrow diagnostic standards in postmortem applications. There is currently no established educational curriculum for PMCT and scarce educational material on forensic radiology [4].

In a clinical setting, intracranial edema is associated with diagnostic criteria such as cerebral and cerebellar herniation, ventricular compression, the lack of a distinction between the basilar cisterns and outer CSF spaces, the effacement of sulci and gyri, and a lack of the GM/WM interface on CT [5–12]. Moreover, in living patients the severity of brain edema has been described using a decreasing ratio of attenuation between GM and WM [8,9,11]. The position of the cerebellar tonsils as related to the foramen magnum is delineated by McRae's line (a line drawn from the basion, which is the inferior tip of the clivus, to the posterior lip of the opisthion). The tonsils are usually located above McRae's line [13]; however, in rare cases, a lower tonsil position is described as being normal [14].

Differences between brain edema as a cause death or as a contributing factor in a lethal case are difficult to assess using PMCT

Abbreviations: CSF, cerebrospinal fluid; DGW, difference of Hounsfield Units between gray and white matter; GM, gray matter; GWR, gray-to-white matter ratio of Hounsfield Units; HU, Hounsfield Units; PMCT, postmortem computed tomography; ROI, region of interest; WM, white matter; SD, standard deviation.

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[2,15–17]. Radiologists tend to use the same criteria for both living and deceased patients in assessing brain edema. However, the differentiation between a pre-existing antemortem (or agonal) brain edema and the typical postmortem generalized brain swelling that occurs immediately after death is challenging when using these clinically known criteria.

Typical postmortem brain swelling appears to initially correspond to a cytotoxic edema, which starts immediately at the time of death, aggravates over time and precipitates concomitant decay such as putrefaction and autolysis [12].

The ongoing loss of differentiation between the WM and GM is predominantly attributed to energy failure (deprivation from oxygen and glucose). This disables the sodium–potassium membrane adenosine triphosphatase pump system with consecutive intracellular water accumulation [18]. A subsequent swelling of the cells sets in, resulting in a blurring of the WM and GM on PMCT [2]. In the absence of adenosine triphosphatase, the muscular filaments become permanently complexed, and rigor mortis sets in until decomposition occurs [18]. However, at some point of decay, vasogenic, cytotoxic, osmotic and interstitial brain edema may be present simultaneously.

In forensic autopsy, there are criteria for antemortem cerebral edema. These criteria are primarily based on the increased cerebral weight caused by edema, as well as the subjective assessment of flattened gyri and filled sulci as well as swollen hippocampus, herniated cerebellar tonsils and a midline shift in cases in which the edema is unilateral [19]. In this scenario, the normal, sharp demarcation between the GM and WM is lost and the WM appears to be paler and softer in consistency [18]. The literature states that at least 1 h and at best 4 h of survival are needed to detect unequivocal histopathological changes in the brain tissue with a preferable short postmortem interval, in order not to overlay subtle findings by autolysis [19]. The challenge presented by cerebral swelling on PMCT is to differentiate between normal physiological postmortem changes and pre-existing pathology (antemortem or agonal developed brain edema).

The purpose of this study was to compare postmortem computed tomography with forensic autopsy regarding their diagnostic reliability to differentiate between pre-existing cerebral edema and physiological postmortem brain swelling and to establish diagnostic criteria for intoxication or asphyxia as the cause of death.

2. Materials and methods

2.1. Study subjects

The department of the public prosecutor approved the study. In retrospect, 200 consecutive subjects with pre-autopsy whole-body PMCT scans, separate head scans and full forensic autopsy, were initially included in the study (from July 2011 to April 2013). Of the 200 cases, 91 cases had to be excluded because of intracranial hemorrhage (n = 20), cerebral primary tumor or metastasis (n = 2), focal/unilateral edema (n = 5), age under 18 years (n = 6) (excluded due to the absence of standard normal brain weight tables in this age), extensive traumatic brain injury (n = 19), thermal impact (charred, hypothermic or frozen bodies) (n = 5), postmortem decomposition (n = 24), hydrocephalus (n = 7) or technical artifacts (n = 3), leaving 109 cases (83 male, 26 female) for analysis. The mean age of the included subjects was 53.2 years (range 20–88 years). The mean time, which elapsed between time of death and PMCT scan (death-to-PMCT interval), was 31 h and varied from 4 h to 199 h. The causes of death were central regulatory failure (n = 4), ex-/ensanguination (n = 12), cardiac failure (n = 48), asphyxia (n = 9), multi-organ/system failure (n = 9), intoxication (n = 24), hypothermia (n = 1), tumor/metastasis (n = 1) and metabolic (n = 1).

2.2. Groups

The subjects were grouped by age for analysis according to the age-dependent changes of the brain parenchyma and the CSF spaces: group 1 (18–35 years, n = 18, 17.3%), group 2 (36–50 years, n = 30, 27.2%), group 3 (51–70 years, n = 42, 38.2%) and group 4 (>70 years, n = 19, 17.3%).

As subgroups, the cases of intoxication (n = 24) and intoxication and/or suffocation (n = 35) were separated from other causes of death, whereas cases with leukoencephalopathy (n = 21) were excluded.

2.3. Forensic autopsy

The autopsy included the external inspection and opening of all three body cavities (skull, thorax and abdomen). The brain weight (g) was routinely measured and documented in each case during autopsy and was supervised by at least one board-certified forensic pathologist. As a correlate of brain edema, the relative deviation of the brain weight over the age-dependent normal values [20] as well as the reduced tissue consistency and flattening of the gyri [21] were used. The autopsy findings served as the reference standard. Histology was not performed for the diagnosis of brain edema. Toxicology was performed in cases with suspected drug abuse or intoxication.

The time elapsed between time of death and autopsy (death-to-autopsy interval) was 41 h and ranged from 5 h to 201 h.

2.4. CT data acquisition and image reconstruction

Image acquisition was performed on a dual-source CT scanner (SOMATOM Flash Definition, Siemens, Forchheim, Germany). The scans were performed after the arrival of the deceased at the Institute of Forensic Medicine and prior to autopsy with 120 kV and automatic dose modulation (CARE Dose4D^{TM}, Siemens, Forchheim, Germany). The imaging included a complete whole-body scan (from head to toe with lowered arms) with an extended field of view (slice thickness of 2 mm), a separate head and neck scan (slice thickness 0.6 mm, increment 0.4 mm, reference mAs 800) with an adjusted field of view (FoV, maximum 300 mm), a separate thorax/abdomen scan with elevated arms (slice thickness 1 mm) with soft tissue and bone window/lung window with (respectively) soft and hard kernel reconstructions. In detail, the image reconstruction of the head and neck further included orbitomeatal and symmetrically aligned axial thick-sliced images (4 mm, 3 mm increment) in a cerebral window in a soft kernel via a 3-dimensional reconstruction tool for multiplanar reconstruction (MPR). Additional multiplanar and 3-dimensional reconstructions were performed at a multimodality workplace (LEONARDO, SynGo, Siemens Medical Solutions, Erlangen, Germany).

2.5. PMCT data analysis

Retrospective image evaluation was performed on a Picture and Archiving Communications System (IDS 7, Sectra, Linköping, Sweden). A board-certified radiologist with 6 years of experience in postmortem forensic radiology reviewed the images and was blinded to the autopsy results and case circumstances. The radiological data analysis regarding the absence or presence of brain edema included the following parameters:

1. Measurements of the inner CSF spaces – the left and right side ventricle.