Forensic Science International 249 (2015) 35–41

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Post-mortem evaluation of drowning with whole body CT

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ARTICLE INFO

Article history:
Received 29 October 2014
Received in revised form 7 January 2015
Accepted 8 January 2015
Available online 19 January 2015

Keywords:
Post-mortem imaging
Whole body
Computed tomography
Drowning
Forensic medicine

ABSTRACT

Purpose: The aim of this study is to investigate the value of whole body computed tomography (WB-CT) in bodies recovered from water by analysis of the imaging findings after drowning.
Methods: The bodies of 41 drowning victims and 9 persons who died from mechanical asphyxia by hanging underwent post-mortem whole body computed tomography.
Results and conclusions: Excessive fluid in the paranasal sinuses (98%), nasal pharynx (98%), oropharynx (95%), trachea (83%), ground glass opacities in the lung (89%), pleural fluid (71%), pericardial fluid (59%), esophageal fluid (81%), stomach fluid and distension (71%), duodenal (34%) and jejunal distension (31%) were the most frequent drowning related imaging findings which significantly differed from the group of mechanical asphyxia by hanging. In cases of fresh water drowning hemodilution was present in 79%. New and up to now unpublished findings were lower density in the spleen, indicative for hemodilution and detection of a pronounced amount of pericardial fluid, only seen in drowning victims.

1. Introduction

The debut of radiology in forensic medicine dates back from the late 19th century, when radiography made its first appearance in the court room [2]. In the last few decades, techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) opened up a whole new range of possibilities to determine cause of death, to provide information in the identification of bodies or the discovering of previous medical conditions. To date, some causes of death are still difficult to determine, in particular when a body is found in water. The key question remains if the individual was dead before entering the water or if "true drowning" was the cause of death [19].

Whether drowning occurs in a suicide attempt, by accident or in relation to an intentional act (such as pushing), the pathophysiology of drowning is a complicated process where different steps can take place: such as breath holding, CO_2 accumulation and water aspiration [8,19]. Depending on the drowning medium, fresh or salt water, a variety of physiological alterations appear such as bronchospasms, electrolyte changes. Another phenomenon is the surfactant deficiency where both fresh and – to a lesser degree – seawater, induces alveolar instability and permeability, resulting in pulmonary edema [8]. Aspiration of seawater leads to an increase in the volume of fluid within the air spaces of the lungs [8]. Additionally the hypertonic seawater pulls fluid from the circulation into the lungs [8]. Hypotonic fresh water causes a massive absorption of water through the alveolar membrane, with an increase in blood volume and hemodilution within minutes. This hemodilution can be visible on CT images as a reduction in blood density [1]. Seawater, on the other hand, causes a hypovolemia and hemoconcentration [8].

In addition, referring to the effects of the different types of drowning medium, even though the majority of drownings are so-called "wet drownings", approximately 10% of drowning cases happens without fluid aspiration, the so-called "dry drownings" [3]. Furthermore, the post-mortem interval between drowning and the recovery of the body, influences the external examination and autopsy findings. During agony and in the early post-mortem period, a plume of froth can be visible around nose and mouth, but

Abbreviations: MRI, magnetic resonance imaging; CT, computed tomography; GGO, ground glass opacity; HU, hounsefield units; WB–CT, whole body CT; IVC, inferior vena cava; ROI, region of interest; FWD, fresh water drowning; SWD, seawater drowning; RA, right atrium; LA, left atrium; RV, right ventricle; LV, left ventricle.

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http://dx.doi.org/10.1016/j.forsciint.2015.01.008
0379-0738/

it is rather transient and can even be absent or washed away when the body was discovered [14,17]. Other external findings such as skin maceration or cutis anserina are mere signs of immersion, than proof of a vital drowning [14]. By internal examination, rather non-specific findings can be present: frothy fluid in the airways, pleural fluid, emphysema aquosum (hyperexpansion of the lungs [8]), froth or foreign material in airways or the digestive system [12,19,20]. To date, the gold standard to substantiate "true drowning" remains diatom investigation, although certain critics and technical difficulties need to be taken into account [14]. Detection of chemical substances (found in water) in the blood of drowned victims, such as strontium and other markers has also been done, but is nevertheless also endowed with difficulties [15,16].

Previous studies on post-mortem computed tomography imaging were conducted on groups ranging from 6 to 39 drowning subjects [1,6]. In maxillary and sphenoidal sinuses, fluid was present in up to 100% of the drowning cases, in the frontal sinus in 70% to 100% and 80% to 100% had ethmoidal fluid [3,11]. In the paranasal sinuses of eleven deaths by asphyxiation (by another manner than submersion in liquid), fluid was present in 78% [18]. Levy et al. found fluid in mastoid air cells in 100% of drowning victims [11].

Up to 93% had fluid in trachea and main bronchi and in 50% there was high-attenuation sediment in trachea or main bronchi [11]. In the lungs the most common finding was the presence of ground glass opacities (GGO), in a mosaic pattern of hypoperfused and hyperperfused lung areas [3,9,11,18]. Pleural effusions were found in approximately 70% of drowning subjects [3,11]. The position of the diaphragmatic dome of drowning subjects is at an average level of the fifth anterior rib, which is lower than in control groups, [3,18].

When the density of cardiac chambers was measured, some studies found a lower density, others found a higher density than in their control group [1,3,18]. In drowning victims the average density of the stomach content was 20 Hounsfield units (HU) and up to 90% had a duodenal distension [3].

2. Materials and methods

2.1. Study cases

We retrospectively reviewed 50 cases which had undergone post-mortem CT between January 2009 and July 2014. Forty-one of the cases, were bodies retrieved from water; 28 males and 13 females. The mean age at death was 58 years, ranging from 15 to 90 years. The majority of the bodies were usually found in fresh water (37 cases), 4 cases were found in seawater. In 11 of these 41 cases, an autopsy was performed, an additional toxicological analysis was performed in 20 external examinations and in all autopsies. The control group consisted of 9 cases, who all died from mechanical asphyxia by hanging. There were 7 males and 2 females, with a mean age of 40 years ranging from 24 to 59 years. As control cases of asphyxia, hanging cases were chosen in order to obtain a homogeneous control group. The cause of death was determined to be drowning or asphyxia after a thorough external examination, and/or autopsy and police investigation. We excluded cases where the cause of death was questioned, due to putrefaction or toxicology results. The average interval between the external examination and the scanning procedure was 7 h, with a maximum of 24 h.

2.2. Image acquisition and assessment

Post-mortem CT in the first hospital was performed using a 32-slice multi-detector CT scanner (Aquillon 32, Toshiba Medical Systems). In the second hospital seven scans were obtained with a 64-slice multi-detector CT scanner (Discovery CT750HD, GE Medical Systems). All subjects were scanned in a body bag, in supine position. The first part of the CT study covered head and neck region, followed by a scan from head to pelvis and a final scan from the pelvis to the feet. Multiplanar image reconstructions were carried out with slices of 3.0 mm thickness, in a bone, lung and mediastinal window. All the images were assessed on a Barco MFGD 3420 monitor with 3-megapixel resolution (using K-PACS V 1.6.0 DICOM Viewing Software Barco, Kortrijk, Belgium). The image assessment was made individually by an experienced board-certified radiologist and a forensic pathologist-in-training. The radiological assessment was performed double-blind: none of them had previous knowledge of the results of the forensic investigation and the circumstances of death. Afterwards discrepancies were discussed and a decision was made by consensus.

2.3. Measured variables: Table 1

2.3.1. Respiratory system

The presence and quantity of fluid in the paranasal sinuses was evaluated. The quantity was expressed in one of three following categories: 1–2 mm fluid, more than 2 mm but less than 50% or filled equal or more than 50% of the volume of the sinus. The thickness of the mucosa was assessed as normal ($<$2 mm) or thickened ($\geq$2 mm). Mastoid air cells were evaluated for the presence of fluid. The different levels of the upper respiratory tract were evaluated for the presence of fluid, debris or foam. Presence and volume of fluid in the trachea was assessed on axial images by measuring the cross sectional areas (empty, $<$25%, $<$50%, $<$75%, $\leq$100%) in three regions: upper third, middle third, lower third. The nature of the content was determined: frothy (foam) or fluid. When the density of the fluid was below 30 HU it was labeled as "watery fluid" and "dense fluid" when the density was equal or higher than 30 HU [3]. Lung patterns were divided into 2 subcategories: ground glass opacities and consolidations. Consolidations appear as a homogeneous increase in pulmonary parenchymal attenuation that obscures the margins of vessels and airway wall. Ground glass opacities appear as hazy increased opacity of lung, with preservation of bronchial and vascular margins [5,10]. For each of the lung patterns the location was evaluated: diffuse, patchy, apical, hypostatic (Fig. 5), anterior, posterior. The pleural fluid in the posterior thoracic cavity of the body in supine position was measured bilaterally.

2.3.2. Thoracic cavity, non-respiratory

The height of the right diaphragmatic dome was evaluated according to the position of the anterior ribs. The density of the blood in the cardiac chambers and inferior vena cava (IVC, at the level between liver and right atrium) was measured. The volume of the IVC was evaluated by measuring the cross-sectional surface. The volume of the right atrium was categorized, based on a subjective qualitative method: collapsed, normal or distension. The width of pericardial fluid as an assessment of the volume was measured in the transverse plane.

2.3.3. Digestive system

The presence of fluid and the nature of the content (fluid or fluid with debris) was determined in the proximal, middle and distal third of the esophagus. The volume of the stomach was calculated with the formula: product of the stomach length, height, depth and $\pi/6$ [3]. The stomach can be distended or non-distended and can contain: gas, fluid, food or debris, sediment, other densities (e.g. pills).

The mean density of the stomach content was measured with a region of interest (ROI) of the homogenous fluid component. Duodenal cross-sectional volume and content was also measured. The density of both the liver and spleen was measured.