Journal of Forensic Radiology and Imaging 3 (2015) 111–116

Contents lists available at ScienceDirect

Journal of Forensic Radiology and Imaging

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

Exact volumetric determination of fluid in the paranasal sinuses after drowning

Sissel B. Lundemose, Christina Jacobsen*, Lykke S. Jakobsen, Niels Lynnerup

University of Copenhagen, Department of Forensic Medicine, Section of Forensic Pathology, Frederik V's Vej 11, 2100 Copenhagen East, Denmark

ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form
29 January 2015
Accepted 18 February 2015
Available online 26 February 2015

Keywords:
Drowning
Paranasal sinuses
Forensic medicine
Computed tomography
Post-mortem
Fluid accumulations

ABSTRACT

Objectives: Diagnosing drowning as a cause of death is challenging for forensic pathologists, as no specific diagnostic markers are known. Studies have reported that drowning victims frequently have more fluid accumulation in the paranasal sinuses.
Purpose: The aim of this study was to calculate the fluid volume in the individual paranasal sinuses compared to the individual sinus volume in deceased who suffered from either wet or dry drowning compared to other non-water related causes of death.
Materials and method: This study retrospectively investigated 27 cases: 10 wet drowning, 7 dry drowning and 10 non-drowning cases. Sinus volume and fluid volume was determined by using segmented postmortem CT-scans.
Results: The results showed that fluid accumulation in the maxillary, sphenoid and frontal sinuses was significantly associated with drowning, although fluid accumulation in the paranasal sinuses, especially the sphenoid sinus, was also seen in some of the non-drowning cases.
Conclusion: We conclude that the presence of fluid in all of the three examined paranasal sinuses can be an indicator in favour of the drowning diagnosis.

1. Introduction

Establishing the manner and cause of death in drowning cases is a challenge for forensic pathologists. Drowning presents considerable diagnostic difficulties, as no specific diagnostic markers are known. In forensic medicine, drowning is diagnosed by an overall assessment of the macroscopic and microscopic findings as well as the circumstances of death, i.e. the body found in water [1]. The most typical findings at autopsy in wet drowning cases, are caused by asphyxiation with aspiration of fluid, and represent froth in the airways, pleural effusion, emphysema aquosum with elevated lung weight and fluid/foreign bodies in the ventricle and airways, including the paranasal sinuses [1]. It is important to note that these findings are not specific for drowning and may be caused by other mechanisms [1]. If the circumstances of death are consistent with positive findings then there is an indication of drowning. Dry drowning cases are characterized by the absence of the mentioned findings. Dry drowning is assumed to occur due to laryngospasm caused by water stimulation. In these cases water is not aspirated into the airways [2].

The usefulness of Computed Tomography (CT) in forensic medicine has become recognized and is now commonly used at forensic institutes around the world [3–8]. At the Department of Forensic Medicine, University of Copenhagen, all bodies brought in for a forensic autopsy are CT-scanned prior to the autopsy. CT-scanning allows visualization of fluid in the paranasal sinuses. Based on CT-scans, other studies have reported that drowning victims have more fluid in the maxillary and sphenoid sinuses than deceased with other causes of death. Christe et al. [9] reported that all their examined drowning cases had significantly more fluid accumulation in the maxillary and sphenoid sinuses than their non-drowning cases. Kawasumi et al. [10] used CT-scan images to measure the amount of fluid in the paranasal sinuses as well as the density of the fluid, based on Hounsfield Units (HU), and they also reported significant differences between the drowning and the non-drowning group. However, they did not take autopsy findings or aspects of wet and dry drowning into consideration, and they also did not compare the volume of fluid in the paranasal sinuses against the paranasal volume as such. The study by Christe et al. [9] only listed whether fluid was present or not, i.e. the volume or the density of the fluid was not determined.

In this study we present exact volumetric determination of the various paranasal sinuses and of the fluid content to differentiate cases of wet drowning, dry drowning and non-drowning. For the same purpose potential density differences of the fluid are

* Corresponding author. Tel.: +45 35326168.
E-mail addresses: stf651@alumni.ku.dk (S.B. Lundemose), christina.jacobsen@sund.ku.dk (C. Jacobsen), lykke.jakobsen@sund.ku.dk (L.S. Jakobsen), nly@sund.ku.dk (N. Lynnerup).

http://dx.doi.org/10.1016/j.jofri.2015.02.003
2212-4780/

determined based on HU. We further tabulate the volumes against the postmortem interval (PMI).

2. Material

We retrospectively reviewed 27 cases from our institution that had undergone post-mortem CT-scanning and forensic autopsy during 2008–2013. The autopsies were performed or supervised by a board-certified forensic pathologist. The cause of death of each case was confirmed by the interactions of macroscopic and microscopic findings as well as the circumstances of death. The study sample included 10 wet drowning cases, 7 dry drowning cases and 10 non-drowning cases (Table 1). The control-group was matched for age, but chosen randomly between other autopsy cases between 2008 and 2013. The non-drowning group included the following causes of death; poisoning ($n=5$), heart disease ($n=2$), unknown cause of death ($n=2$) and/or internal haemorrhages ($n=1$). We excluded cases with pronounced decomposition, because the formation of decomposition fluid could cause false positive results. Furthermore we excluded cases with anamnestic information about trauma against head, neck and/or thorax, because it would impede a correct segmentation of the anatomical structures, cases with anamnestic information about infections in the respiratory tract, because tissue exudate also could cause false positive results and sub-adult cases, because of the not fully developed paranasal sinuses [11].

At the case review and based upon the autopsy reports, the following parameters were registered: age, sex, time of death, an estimate of time (in days) since death (the post-mortem interval, defined as the last time the person was seen alive until the person was found dead), degree of putrefaction, presence of waterlogged skin ("washer"-woman's skin or hands), adipocire, dermal abrasions and thoracic findings such as lung emphysema, oedema aquosum, froth in the airways, elevated lung weight and pleural effusion. These parameters were important in order to ensure that the grouping of dry- and wet drowning was performed as correctly as possible. The circumstances of the scene were also registered (Table 2).

3. Method

The CT-scans were performed using a 4-channel multi-detector row CT-scanner (Somatom Plus 4, Siemens, Germany). Axial slices were acquired with a tube voltage of 120 kV. The acquired slice thickness was 3 mm with a pitch of 2.5. Axial, coronal and sagittal reformations were calculated for soft tissue and bone.

The reformatted CT image data were imported to Mimics (Materialise, Leuwen, Belgium). The maxillary, sphenoid and frontal sinuses and the fluid within them were segmented manually on a slice-by-slice basis (about 200–300 image per case per sinus), Figs. 1 and 2. We then calculated volume data of both sinuses and the fluid, as well as the average density (HU) of the fluid. The different cases were blinded for the person who carried out the measurements and each of the segmentations was examined between three and four times.

The Kruskal – Wallis test was used to assess the relationship between the drowning diagnosis and fluid accumulations in the maxillary, sphenoid and frontal sinuses and also to evaluate if there was an association between the density of the fluid and cause of death.

Table 1
The 27 cases divided by gender, age and cause of death.

	Wet drowning		Dry drowning		Non- drowning		Total
	N	Avg. age (span)	*N*	Avg. age (span)	*N*	Avg. age (span)	*N*
Males	7	54 (40–79)	5	48 (38–55)	7	47 (29–71)	19
Females	3	68 (48–84)	2	58 (54–62)	3	47 (26–76)	8
Total	10		7		10		27

4. Results

Table 3 shows the volumetric results by sex. As expected, the males had overall larger sinuses (except for the right sphenoid sinus), but the females had overall the greatest total amount of fluid in the sinuses. There was no clear pattern in the overall distribution of present fluid based on sex or sinus volume. Some fluid was present in one or more sinuses in all cases.

However, a clear pattern was present for the drowning and non-drowning groups: The average amount of fluid (percentage) in the wet and dry drowning group was almost equal (wet drowning 24%, dry drowning 28%), while the non-drowning group had a significantly lower amount of fluid ($p=0.017$) (Table 4 and Figs. 3 and 4).

In Fig. 4 a purely visually determined line, is drawn at a fluid content of 14% and would correctly assign overall 20/27 cases to their respective groups, with 7/10, 6/7 and 7/10 to the wet drowning, dry drowning and non-drowning cases, respectively. Based upon the results from Fig. 4 the sensitivity and specificity between the drowning groups and the non-drowning group was calculated to 0.77 and 0.70.

Regarding the distribution pattern of the fluid in the different sinuses there frequently seems to be fluid in the sphenoid sinuses regardless the grouping. The frontal sinuses seemed to contain more fluid in the drowning cases than in the non-drowning cases (Table 5).

However, in the non-drowning group, we found that in 4/10 cases fluid was only present in the sphenoid sinuses, and in further 2/10 cases, the sphenoid sinuses contained the most fluid (data not shown).

The post-mortem interval in days was compared with the total amount of fluid in the paranasal sinuses (Fig. 5). The majority of cases had a PMI around 5–6 days. Most of the non-drowning group had the lowest amount of fluid except one (nr. 27) where the cause of death was poisoning. The results were rather variable for the drowning cases (wet and dry) and no clear pattern was seen.

Table 2
Circumstances of the scene.

	N	Circumstances of the scene	Type of water
Wet drowning	1	Body found in the fjord	Freshwater
	1	Body in the bathtub, head breaking surface	Freshwater
	1	Body submerged in the bathtub, attempted resuscitations	Freshwater
	4	Body complete submersed in the ocean	Saltwater
	2	Body found at the beach, head submerged	Saltwater
	1	Head and torso in the ocean, attempted resuscitations	Saltwater
Dry drowning	5	Body submerged in a lake	Freshwater
	2	Body in the docks	Saltwater