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Epidemiology and autopsy findings of 500 drowning deaths

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ABSTRACT

Introduction: Drowning is a significant public health problem worldwide and the WHO reported that drowning is the world's third leading unintentional injury death. Nevertheless, there is still uncertainty regarding the estimate of local and global drowning deaths. In addition, the postmortem diagnosis of drowning is challenging and the physiological mechanisms of death by drowning are complex and not very well understood.
Purpose: To analyze a large series of bodies retrieved from the water in Connecticut (U.S.) in order to compare epidemiologic and toxicological data with those of the literature, as well as to examine the weights of the lungs and brains in drowning deaths.
Material and method: We conducted a descriptive, retrospective, population-based analysis of all bodies retrieved from the water and subjected to a forensic autopsy at the Office of the Chief Medical Examiner in Connecticut (2008–2020, n = 500). Variables collected were sex, age, date of death, location of drowning, season, type of water, cause of death, manner of death, circumstances of death, signs of decomposition, BMI, brain weight, lung weight, presence of pulmonary edema, stomach contents, and toxicological analysis.
Results: The death rates of drownings in Connecticut ranges from 0.75 to 1.28/100,000/year. They occurred predominantly in males (73.4%) and most were accidents (75.6%), though this gender difference diminishes in suicides (55.4% of males). Sex distribution is also different in bathtub drownings, where women drown more frequently (67.3%). Weights of the brains ($p = 0.013$) and lungs ($p < 0.001$) were higher in saltwater drownings.
Conclusions: Drowning is more frequently an accident involving men, except for suicides where there is only a slight difference among sex. Heavy lungs and cerebral edema continue to be identified in numerous drowning deaths. These anatomic findings, however, must still be interpreted in the context of the entire case investigation. Weights of the brains and lungs are higher in salt water, although these organs' weights are mostly dependent on other variables such as BMI and decomposition.

1. Introduction

Drowning is the process of experiencing respiratory impairment from submersion/immersion in liquid; it is essentially an "asphyxial" death [1]. Drowning is a significant and neglected public health problem worldwide and, thus has received attention from the WHO [2]. Their report described how drowning is responsible for an estimated 372,000 fatalities in 2012, making it the world's third leading unintentional ("accidental") injury death. For every fatal drowning, there are approximately four non-fatal drowning victims who come for medical care. Of these, half require hospital admission and interventions [3]. The WHO's goal is to implement strategies for prevention in order to decrease these deaths, particularly in children and young people (drowning is one of the 10 leading causes of death for people aged 1–24 years in every region of the world). In addition to age, other risk factors include warm southern geographic regions, concomitant drug or ethanol use, and epilepsy [3].

From epidemiologic studies of drowning's series of cases [2,4–12], the following data can be deduced:

- Drowning rates range from 2 to 8/100,000/year. Every year in the U.S. there are an estimated 3960 fatal unintentional drownings, including boating-related drowning. That is an average of 11

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drowning deaths per day. Drowning death rates vary by state. The annual age-adjusted drowning death rate in the United States during 2015–2019 was 1.23 deaths per 100,000 people (including boating-related drowning deaths). In Connecticut, age-adjusted unintentional drowning death rate during 2015–2019 was 0.68 per 100,000 [13].
- Drowning is more common among young people (those under 25 years). According to data from Australia, Finland and United Kingdom, drowning is the second leading cause of death among children aged 1–4 years.
- Drowning fatality rates are greater in men than in women (men ranging from 75% to 90% and women ranging from 10% to 25%), though this difference decreases in suicides (54% men, 46% women) [5].
- For manner of death, accidental manner (ranging from 70% to 90%) is most common followed by suicide (ranging from 4% to 20%) and homicide (0.1–2.5%).

Despite these studies, there is still uncertainty regarding the estimate of local and global drowning deaths. Official data categorization methods for drowning usually exclude intentional drowning deaths (suicide or homicide) and drowning deaths caused by flood disasters and water transport incidents, which results in underrepresentation of the full drowning toll. Several studies reveal information on the cost impact of drowning, which is higher in low and middle-income countries where drowning death rates are greater. In the United States, 45% of drowning deaths are among the most economically active segment of the population. Coastal drowning in the United States alone accounts for US$ 273 million each year in direct and indirect costs. In Australia and Canada, the total annual cost of drowning injury is US$ 85.5 million and US$ 173 million respectively [14].

One reason for the uncertainty of the number of drowning deaths is that the postmortem diagnosis of drowning is challenging. Investigation of bodies recovered from water involves an autopsy with toxicological and microscopic studies along with a thorough investigation of the circumstances. The key question is whether the victim died from the submersion or did the submersion occur after death. Unfortunately, "true" drownings are not always easily diagnosed [15,16]. At autopsy, there are no pathognomonic findings to diagnose drowning [17,18]. Instead, the diagnosis is based upon two factors. First, the history and circumstances are consistent with a drowning. Second, the autopsy fails to disclose a disease or physical injury whose extent or severity is inconsistent with continued life. In addition, there are a variety of non-specific ("soft") anatomical findings that may be considered. A complete autopsy including toxicological analysis is required as drowning is a diagnosis of exclusion [19].

The purpose of our study was to analyze a large series of bodies retrieved from the water in Connecticut (U.S.) in order to compare epidemiologic and toxicological data with those of the literature, as well as to examine the weights of the lungs and brains in drowning deaths.

2. Material and methods

2.1. Design and setting

We conducted a descriptive, retrospective, population-based analysis of data for all bodies retrieved from the water and subjected to a forensic autopsy at the Office of the Chief Medical Examiner (OCME) in Connecticut, from 2008 through 2020. The Connecticut OCME is a state-wide medicolegal death investigation system. By statute, all unexpected, unnatural, and suspicious deaths that occur in Connecticut must be reported to and investigated by the OCME. During this time frame, the Connecticut OCME performed approximately 1 400–3 000 autopsies per year.

2.2. Data collection and analysis

The total number of drowned bodies were 500 from 1 January 2008–31 December 2020. Variables collected were sex, age (years), date of death, location of drowning, season, type of water (salt/fresh water which also included pool and bathtub water), cause (s) of death (drowning/near drowning/drowning + intoxication/ drowning + other causes), manner of death, circumstances of death (based on police and OCME investigators), signs of decomposition (present/absent), height (cm), weight (g), BMI (kg/m^2), brain weight (g), lung weight (g), presence of gross pulmonary edema (present/absent), stomach contents (ml), and toxicological results (negative/ethanol/ethanol + other drugs/none taken). The criteria that we used for decomposition was any macroscopic signs of putrefaction such as skin discoloration (from reddish-green to black) or marbling/bloating/skin blisters/blebs, foul odor, etc. We diagnosed pulmonary edema based on the weight and presence of foam/fluid in the trachea/bronchi/cut surfaces.

A diagnosis of death due to drowning was made when the history and circumstances are consistent with a drowning and the autopsy fails to disclose a disease or physical injury whose extent or severity is inconsistent with continued life. Submersion in water alone is insufficient to make a diagnosis of drowning as some people may succumb to natural disease (sudden cardiac death) while in the water.

Postmortem blood was collected, preserved with sodium fluoride, and stored at 4 °C. In-house and NMS Labs performed the toxicology testing. Ethanol concentrations were determined in blood using head space gas chromatography. Specimens were routinely screened for opioids, barbiturates, amphetamines, benzoylecgonine (BE), and benzodiazepines by enzyme immunoassay and/or high-performance liquid chromatography/Time of Flight-Mass Spectrometry with some confirmations using gas chromatography/mass spectrometry (GC/MS).

2.3. Statistical methods

All data were analysed using the PASW Statistics 25 software (IBM-SPSS®) for Windows. Continuous measures were summarized as mean and standard deviation (SD) when the distribution of data was normal (Kolmogorov-Smirnov test); otherwise, as median and interquartile range (IQR). Categorical variables were reported as frequencies and proportions. In addition to the descriptive analysis, a comparison of proportions for the qualitative variables between the different groups was made using the Chi square ($\chi 2$) test for contingency tables, applying the Finner correction for multiple comparisons. Statistically significant differences for each category were obtained using corrected typified residues analysis (absolute values > 1.96). In the case of normal distribution continuous variables, comparisons of average values were conducted by T-student test and one-way analysis of variance (ANOVA), applying the Games-Howell and Scheffé post hoc tests. Non-parametric tests, such as the Kruskal- Wallis test and the Mann-Whitney *U* test were also conducted. To determine the variation between the weights of the organs and the rest of the variables, the linear regression test was applied. The Pearson or Spearman correlation tests were also made on the continuous variables. Statistically significant values were those with a confidence level over 95% ($p < 0.05$).

3. Results

Socio-demographic and circumstantial features of the autopsied cases are shown in Table 1.

Table 1
Characteristics of the autopsied cases.

		N = 500
Socio-demographic data	Sex	
	Males	367 (73.4%)
	Females	133 (26.6%)
	Age (years)	
	Mean ± SD	43.15 ± 22.37
	Drowning death rate [20]	0.75 – 1.28/100,000/year
Season	Winter	62 (12.4%)
	Spring	150 (30%)
	Summer	215 (43%)
	Autum	73 (14.6%)
Type of water	Fresh water	410 (82%)
	Fresh (river, lake, etc.)	291 (71%)
	Pool	64 (15.6%)
	Bathtub	55 (13.4%)
	Salt water	90 (18%)
Manner of death	Accident	378 (75.6%)
	Suicide	83 (16.6%)
	Homicide[a]	5 (1%)
	Undetermined	34 (6.8%)

[a] The five homicides included three infant/pediatric deaths (2 in a bathtub, one thrown into a river) and two adults (one assault with push into a river and the other a murder-suicide by driving a car into a lake).

Table 2
Autopsy findings.

Cause of death	Drowning	451 (90.2%)
	Near drowning	11 (2.2%)
	Drowning + drug intoxication	21 (4.2%)
	Drowning + other causes[a]	17 (3.4%)
Toxicological results	Negative	207 (41.4%)
	Ethanol positive	129 (25.8%)
	Positive to other drugs	73 (14.6%)
	Positive to ethanol + other drugs	84 (16.8%)
	None taken	7 (1.4%)
Decomposition	Yes	82 (16.4%)
	No	418 (83.6%)
Pulmonary edema	Yes	305 (61%)
	No	195 (39%)
BMI	Mean ± SD	
	Men	25.57 ± 5.63
	Women	24.59 ± 5.81
Organ Weights	Brain (Mean ± SD)	
	Males	1432.3 ± 149.47
	Females	1297 ± 120.49
	Left Lung (Mean ± SD)	
	Males	625.72 ± 240.85
	Females	522.66 ± 218.31
	Right Lung (Mean ± SD)	
	Males	688.1 ± 255.85
	Females	588.14 ± 240.71
	Combined lungs' weight (Mean ± SD)	
	Males	1313.82 ± 485.46
	Females	1110.79 ± 446.88
Stomach Contents	Yes	445 (89%)[b]
	No	55 (11%)

[a] Other previous medical conditions were involved in the cause of death: seizures, epilepsy, viral myocarditis, cerebrovascular, and cardiac disease.
[b] > 500 ml= 41 (8.2%)

Autopsy findings are summarized in Table 2.

In relation to the statistical comparisons of the studied variables, the main results are summarized in Tables 3 and 4, and Fig. 1:

The type of water has a significant relationship with differences in the weight of the brain and lungs, being always higher in salt water than in fresh water (Table 3, Fig. 1). Nevertheless, this statistically significant relationship losses significance when the weights of the organs are corrected by BMI. Sex has a significant relationship with BMI, being higher in males than females (25.57 versus 24.59; $p = 0.042$). Age has a weakly positive correlation with BMI and the weight of the lungs (R ranging from 0.212 to 0.268; $p < 0.001$).

Decomposition has a statistically significant relationship to the season ($p < 0.05$), mainly at the expenses of the higher percentage of decomposition in spring (Fig. 2). It is also related to the lower weight of all organs (Table 3).

Finally, a multiple linear regression analysis in relation to the weight of each of the organ types was done (Table 5). The greatest predictive power was shown by the models for the weight of the left lung and the combined weights of both lungs (adjusted $R^2 = 0.261$), followed by the right lung (adjusted $R^2 = 0.238$) and the brain (adjusted $R^2 = 0.231$). For the lungs in general, the variables that have shown the greatest predictive capacity were the presence of decomposition and the sex of the individual. For the brain, in addition to sex, BMI played an important role.

4. Discussion

Drowning is mainly an "asphyxial" process with effects on multiple organ systems, though the lungs are the primary organs affected [18]. Nevertheless, physiological mechanisms of death by drowning are complex and not very well understood. Following the classic studies in animals by Brouardel and Vibert in the late 19th century, the pathophysiology of drowning has progressed little and continues with different theories [21].

Apart from the effects of the resulting hypoxia on tissues, other possible mechanisms responsible for cardiovascular alterations have been proposed, such as electrolyte changes with possible different effects between hypotonic freshwater and hypertonic saltwater immersions [22,23]. In addition, some authors have considered the role of cold water in relation to hypothermic cardiovascular effects [24], as well as a different mechanism of death underlying “dry drowning” in a small percentage of cases, without apparent inhalation of water [25,26].

Males predominant in drownings (73.4%), in accordance with all the literature [4,7,11,12,27]. Nevertheless, this difference diminishes in suicides, having noted 55.4% of males in our series, in accordance with the findings of Wirthwein et al. [5] who found 54% of males. The sex distribution also differs in bathtub drownings, where women drown more frequently (67.3% women). This was due in part to the manner of death, as all 11 suicides among 55 bathtub drownings were females.

Other variables related to sex are the toxicological results ($p < 0.001$): the percentage of ethanol positivity is higher in men, while for women, the percentage of other drugs is higher. 291 of 500 cases (58%) were positive for ethanol and 84 (16.8%) with other drugs of abuse. Our results are very similar to those of Kringsholm et al. [4] who found a concentration of more than 0.1 gm% ethanol in 53%. Similarly, Lunetta et al. [7] noticed that ethanol was a contributing factor in 51.6% of drowning deaths among victims of all ages. Finally, we noted differences according to sex ($p = 0.002$) with regard to the cause of death with "Drowning + Toxicology" more frequent with females, probably because in relative terms suicide by drowning and association to drugs are more frequent in females.

Drownings in bathtubs are somewhat unique in that it is highly unlikely for adults to drown in a bathtub unless the person is unwilling or unable simply to lift one's head above the water. If a person is unwilling to lift their head above water, the death would be certified as a suicide. If the person is unable, it may be a homicide (being held down) or due to an intoxication or an incapacitating natural disease (e.g., epilepsy). Since it may be difficult to distinguish a death due to drowning from one due to an intoxication, the suicidal bathtub death may be certified with both causes. This is a recognition that the person may have drowned or may have succumbed to the intoxication and then slid under water. When both scenarios are reasonable explanations for death, one may include

Table 3
Relationship between the weight of the organs and other characteristics.

		Brain weight (g)		Left lung weight (g)		Right lung weight (g)		Combined lungs weight (g)	
		Mean ± SD	p value	Mean ± SD	p value	Mean ± SD	p value	Mean ± SD	p value
Decomposition	Yes	1355.31 ± 181.13	0.02	421.11 ± 114.53	< 0.001	42.72 ± 141.89	< 0.001	893.83 ± 244.49	< 0.001
	No	1404.88 ± 147.37		633.12 ± 241.97		698.58 ± 256.58		1331.71 ± 486.39	
Type of water	Fresh	1390.25 ± 153.79	0.013	587.17 ± 240.58	0.009	650.01 ± 254.68	0.015	1237.18 ± 483.84	< 0.001
	Salt	1433.07 ± 141.81		656.13 ± 220.21		721.53 ± 246.41		1377.66 ± 455.2	
Pulmonary edema	Yes	1415.91 ± 145.91	< 0.001	638.07 ± 236.55	< 0.001	703.32 ± 249.37	< 0.001	1341.39 ± 473.33	< 0.001
	No	1367.96 ± 162.23		535.85 ± 230.54		595.79 ± 251.9		1131.64 ± 472.57	

Table 4
Type of water, cause of death and toxicological findings according to sex.

		Sex		
		Male	Female	p value
Water	Fresh	238 (64.7%)*	54 (40.9%)*	< 0.001
	Pool	40 (10.9%)*	24 (18.2%)*	
	Bathtub	18 (4.9%)*	37 (28%)*	
	Salt	72 (19.6%)	17 (12.9%)	
COD[a]	Drowning	338 (91.8%)*	113 (85.6%)*	0.002
	Near Drowning	8 (2.2%)	3 (2.3%)	
	Drowning + Toxicology	8 (2.2%)*	13 (9.8%)*	
	Drowning + other causes	14 (3.8%)	3 (2.3%)	
Toxicology	Negative	161 (43.8%)	46 (34.8%)	< 0.001
	Ethanol	108 (29.3%)*	21 (15.9%)*	
	Other drugs	40 (10.9%)*	33 (25%)*	
	Ethanol + other drugs	55 (14.9%)	29 (22%)	
	Non taken	4 (1.1%)	3 (2.3%)	

[a] COD: Cause of death.
* Statistical significance.

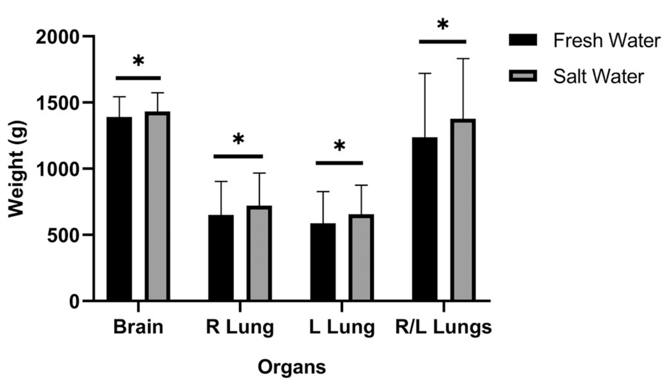

Fig. 1. Mean ± SD of the weight of organs depending on the type of water (* statistically significant differences with different p values -Table 3).

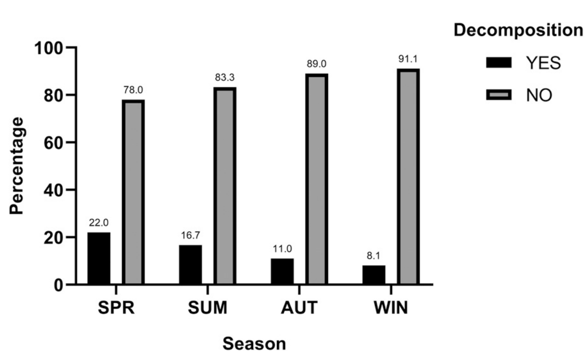

Fig. 2. Decomposition according to the season.

both causes; this is known as "covering the waterfront". Toxicology results usually are not included in the cause of death statement unless the intoxication plays a physiologic role in causing death (e.g., typical "overdose") or the death does not make sense without the intoxication (e.g., drowning in a bathtub, positional asphyxia).

Decomposition involves loss of water by the body and organs. Bodies typically weigh less than they would during life or shortly after death [28]. Our study has also demonstrated that decomposition causes a statistically significant decrease in weight of certain organs (both in absolute terms and corrected by BMI; $p < 0.001$) (Table 3). As the weight of some organs is key to diagnosing potentially fatal diseases (such as cardiac hypertrophy for hypertensive cardiovascular disease), one must take these decompositional changes into consideration when evaluating the "pathologic" weight of certain organs. Decomposition hampers the detection of pulmonary edema as it is more frequently diagnosed in non-decomposed remains ($p < 0.001$).

Finally, decomposition is clearly related to the season ($p < 0.05$), demonstrated by the higher percentage of decomposition in spring (Fig. 2) followed by summer. A study of bodies found floating in the waterways of New York City, found that the most common time to find these bodies was in the spring [29]. The likely explanation is that bodies that go into the water during the winter stay submerged until spring when the water starts to warm up. As the water warms, putrefaction of the bodies increases, and they become more buoyant, float to the surface, and are discovered. New York City and Connecticut are in the same climate region of the northeastern United States.

The extent of putrefaction in any death is largely driven by time and temperature. Water, compared to air, tends to slow the decompositional process. The time factor depends upon how quickly the body is recovered. Because most bodies will sink, there may be a delay in recovery. If a person is not witnessed to submerge or if the submerged body is not visible, the body may only be found many days later after putrefaction has started. Putrefaction results in gas formation in the body by the proliferating microorganisms. This gas will increase the body's buoyancy and it will float to the surface. It is then more likely to be discovered.

The majority of decedents had measurable stomach contents, but only 8.2% has a volume greater than 500 ml. This is similar to the results of Martín-Cazorla et al. [27] who found 12.8% of drowned bodies with similar volumes. Some people may "swallow" water during the drowning process but apparently not all. Decomposition also will decrease the volume of stomach contents.

In relation to the weight of the organs, some have written about differences in the type of water in relation to the mechanism of death [22,23]. For example, some have examined blood electrolyte disturbance differences between hypotonic freshwater and hypertonic saltwater immersions. In fact, early studies (e.g., Gettler chloride test) for the "diagnosis" of drowning used differences in electrolyte concentrations in blood between the left and right chambers of the heart [30]. A later study by Modell and Davis [31] showed this to be incorrect. The high salinity of seawater, whose osmolarity exceeds that of blood, may cause intense pulmonary

Table 5
Coefficients of regression models, and p-values for organ weights.

Models		Unstandardized Coefficients		Standardized Coefficients	t	p value
		B	95% Confidence Interval	Beta		
Brain weight	*(Constant)*	1281.589	1221.977–1341.201		42.242	< 0.001
	BMI	5.380	3.260–7.499	0.198	4.987	< 0.001
	Sex[a]	-139.693	-167.321–112.065	-0.400	-9.935	< 0.001
	Pulmonary edema[a]	41.682	16.102–67.262	0.132	3.202	0.001
	Decomposition[a]	-57.805	-92.141–23.470	-0.138	-3.308	0.001
Left lung weight	*(Constant)*	397.123	303.138–491.109		8.302	< 0.001
	Age	2.007	1.150–2.864	0.188	4.600	< 0.001
	BMI	5.541	2.180–8.902	0.131	3.239	0.001
	Sex[a]	-138.017	-180.890–95.143	-0.255	-6.325	< 0.001
	Pulmonary edema[a]	70.239	30.647–109.830	0143	3.486	0.001
	Decomposition[a]	-201.053	-254.173–147.933	-0310	-7.437	< 0.001
Right lung weight	*(Constant)*	390.375	291.481–489.270		7.756	< 0.001
	Age	2.698	1.795–3.600	0.236	5.876	< 0.001
	BMI	7.087	3.551–10.623	0.157	3.938	< 0.001
	Sex[a]	-138.670	-183.783–93.557	-0.239	-6.040	< 0.001
	Pulmonary edema[a]	74.592	32.932–116.251	0.142	3.518	< 0.001
	Decomposition[a]	-208.691	-264.585–152.796	-0.301	-7.336	< 0.001
Combined lung weight	*(Constant)*	787.499	600.423–974.574		8.271	< 0.001
	Age	4.705	2.998–6.411	0.218	5.417	< 0.001
	BMI	12.628	5.938–19.317	0.148	3.709	< 0.001
	Sex[a]	-276.686	-362.025–191.348	-0.253	-6.370	< 0.001
	Pulmonary edema[a]	144.830	66.025–223.636	0.146	3.611	< 0.001
	Decomposition[a]	-409.743	-515.477–304.009	-0.312	-7.614	< 0.001

Pulmonary edema: present vs. absent.
Decomposition: present vs. absent.
[a] Sex: females vs. males.

edema, which may be less evident in freshwater drownings. Except in the few cases of “dry drowning” the main effects of drowning are related to lungs after inhalation of significant amounts of water. Because of the effect of water in lungs they usually will appear voluminous, boggy, and crepitant with apposition or overlapping of the medial edges. Transudate fluid in the form pleural effusions may be present [18]. In accordance with this fact, we have found macroscopic pulmonary edema in 61% of the bodies (in the whole sample but has to take into account that this figure also includes putrefied bodies where pulmonary edema is more difficult to diagnose).

Lung weights typically are increased in drowning deaths compared with other causes of death [32]. One may observe combined weights of more than 1 kg for adults [33]. Most authors have not observed significant differences between fresh and saltwater cases [4,32], but in our series there were differences in the weight of lungs, being always higher in salt water than in fresh water (Table 3). These results are concordant with Martín-Cazorla et al. [27], who found higher lung weights in salt water in relation to freshwater drowning mainly in men.

In our study, the brain weights followed the same pattern as the lung weights. With salt water, there will be an osmotic shift of water from the pulmonary vasculature into the pulmonary alveoli to equalize the osmolality. It is not clear how this process would also affect the brain weight.

Nevertheless, this statistically significant relationship (differences in weight among salt and fresh water) is lost when the weight of the organs is corrected by BMI. The interpretation of this finding may be that edema in organs because of hypertonic salt water is more frequent and intense, but the weight of the organs is more influenced by the BMI (there is a positive and direct correlation between both parameters).

5. Conclusions

Our review of the epidemiologic, autopsy, and toxicological data from 500 drowning deaths found considerable agreement with those of the scientific literature. Drowning is more frequently an accident involving men, except for suicides where there is only a slight difference among sex. Weights of the brains and lungs are higher in salt water, although these organs' weights are mostly dependent on other variables such as BMI and decomposition. There will always be some drowning deaths with normal organ weights. Heavy lungs and cerebral edema, however, continue to be identified in numerous drowning, as well as near-drowning, deaths. Therefore, these anatomic findings must still be interpreted in the context of the entire case investigation. Use of this information may help to diagnose drownings and also help to identify risk factors to prevent them.

Credit authorship contribution statement

Eloy Girela-López: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Cristina M. Beltran-Aroca**: Formal analysis, Methodology, Writing – original draft. **Amanda Dye**: Data curation, Resources. **James R. Gill**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Declaration of Competing Interest

None.

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