Comparison between lung weight and blood strontium in bodies found in seawater

J.E. Azparren a,*, C. Cubero b, E. Perucha c, P. Martinez a, G. Vallejo a

a Instituto Nacional de Toxicología y Ciencias Forenses (Madrid), Ministerio de Justicia, Luis Cabrera 9, 28002-Madrid, Spain
b Instituto Vasco de Medicina Legal, Servicio de Patología Forense, C/Berroeta Aldamar 10, Bilbao, Spain
c Laboratorio de Enfermedades del Sistema Inmune, Unidad I+D Asociada al CNB-CSIC, Departamento de Medicina, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, Spain

Received 20 October 2005; received in revised form 29 June 2006; accepted 2 July 2006

Abstract

This paper examines the use of lung weight increase as an indicator of seawater drowning compared to the amount of Sr absorbed by the blood. The study population was limited to male victims older than 20 years. Significant differences between cases of drowning and “non-drowning” were detected in terms of the lung–heart weight ratio (L/H) (p < 0.001) or lung–body weight ratio (L/B) (p = 0.005). However, using lung weight (L), L/H or L/B to distinguish between seawater drownings and saltwater non-drownings some overlap was produced. The factor rendering least overlap was L/B, which also appeared to be non-dependent on the victim’s age. Our findings suggest that a value of L/B higher than 19.5 g/kg could be a useful indicator of death by drowning, but that when a lower value is found, additional drowning diagnoses would be needed to establish the manner of death.

Keywords: Drowning; Dry lung; Lung weight; Strontium; Bodies found in water

1. Introduction

Lung weight increase is a well-known autopsy finding related to the drowning process that has recently been linked to the amount of liquid inhaled by the lungs, thus providing information on the manner of death. Lung weight increase has been determined by the different authors as: lung weight [1], the lung–heart weight ratio [2], combined lung and pleural effusion weight [3] or simply by lung weight corrected for body weight [3].

In seawater drownings, lung weight increases from an estimated value of around 234 g [4] to a median lung plus pleural effusion weight of 1360 ± 595 g [2]. However, this weight increase is not only the direct result of water aspiration, since pulmonary alveolar damage and cardiac pump failure also contribute to this weight increase [5,2]. Previous authors have reported lung weights of 975 ± 350 or 889 ± 306 g in cases of acute myocardial infarction/ischemia and asphyxiation, respectively, in deaths unrelated to water immersion [2]. Discrete increases in lung weight have even been attributed to other causes, such as lung oedema, blood congestion due to extrathoracic trauma, etc. [4]. These contributions to lung weight can be a problem when assessing cases of scarce water aspiration in sudden water deaths or when trying to identify “true” dry-drownings [6].

In addition, several factors may limit the capacity of lung weight as an indicator of drowning. These limitations include its dependency on the gender and age of the subjects [3], as well as significant decreases in lung weight after a 3-day postmortem interval (PMI) [3] or an even earlier decrease due to postmortem transudation of pleural effusion [2]. A further limitation of the use of lung weight increase as a marker of drowning is the difficulty in distinguishing between “true” drownings (as defined in Section 2) and other types of death occurring in water. For this purpose, the blood Sr level could help to diagnose some sudden deaths in water that could easily (based on morphological features) be misdiagnosed as deaths due to drowning. According to our experience, a Sr level of 172 µg/L measured in left ventricular blood serves to distinguish seawater drownings from seawater “non-drownings” [7].
By definition, drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium [8]. In this generally accepted definition of drowning, it is explicit that sudden deaths due to water-induced reflexes, such as hydrocution are considered drownings. However, for practical reasons the term ‘drowning’ is used here to denote drownings in their variety of asphyxia, such that sudden deaths produced by any mechanism other than asphyxia induced by immersion in water are not referred to as drownings.

Thus, by definition, drownings are ruled out if death occurred in less than 2 h of the postmortem interval (PMI). In cases with a longer interval, the determination of drowning was made by considering that the body had spent at least 24 h in water. Finally, in cases with an interval between 2 and 24 h, the attribution of drowning was considered as possible if at least one parameter suggested its occurrence. This definition is in agreement with those proposed by other authors [11–13].

To avoid confusion with deaths resulting from immersion in water whose cause of death had not been always clearly established, Drownings were also distinguished from ‘non-drownings’ according to left ventricular blood Sr levels. These last results were found to discretely overlap diagnoses based on factors related to increased lung weight (L) [8].

2. Materials and methods

2.1. Materials

2.1.1. Materials

By definition, drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium [8]. In this generally accepted definition of drowning, it is explicit that sudden deaths due to water-induced reflexes, such as hydrocution are considered drownings. However, for practical reasons the term ‘drowning’ is used here to denote drownings in their variety of asphyxia, such that sudden deaths produced by any mechanism other than asphyxia induced by immersion in water are not referred to as drownings.

This retrospective study was performed on 55 bodies (group A) recovered from Atlantic waters off the northern Spanish coast. In all cases, the drowning medium showed Sr concentrations higher than 3000 μg/L. Victims were excluded if they survived for a short period after being rescued from the water or if they were found dead in the water after >48 h of the PMI.

2.1.2. Methods

Among the seawater bodies examined, significant differences were detected in L, L/H, L/B, body weight (B) and heart weight (H) between drowned and non-drowned individuals, as defined by left ventricular blood Sr levels. Significant differences were also observed in L/H, L/B, H and B between the two groups when the non-drownings were taken as eye-witnessed rapid deaths as described for group B in Section 2 (Table 1).

2.2. Statistical analyses

The Kolmogorov–Smirnoff test was used to assess the normal distribution of variables, revealing a significant distribution abnormality of the data (data not shown). Hence, the data were described in terms of medians and ranges. Differences between independent samples were established using the Mann–Whitney test and correlations between variables by the Spearman’s rho correlation coefficient. The level of significance was set at p < 0.05. All statistical analyses were performed using SPSS v11.0 software.

3. Results

3.1. Lung weights in drownings versus non-drownings

Among the seawater bodies examined, significant differences were detected in L, L/H, L/B, body weight (B) and heart weight (H) between drowned and non-drowned individuals, as defined by left ventricular blood Sr levels. Significant differences were also observed in L/H, L/B, B and H between the two groups when the non-drownings were taken as eye-witnessed rapid deaths as described for group B in Section 2 (Table 1).

3.2. Relationship between lung weight and the age of drowned individuals

Since H is positively correlated with age [11] (Tables 2–4), the dependency of L/H on age is clear for groups A, B and C. The variables L and L/B also show age dependency in group A since this group contains a large number of confirmed deaths of subjects >60 years due to cardiac disease. In group B, there is also a dependency between lung weight increase and age. This relationship with age, however, does not exist for L/B in group B or C.

3.3. Relationship between cold/warm water and lung weight

By comparing lung weights for drownings occurring in warm versus cold water, a significant difference was only
Table 1
Relationship between lung weight increases in drownings and non-drownings

<table>
<thead>
<tr>
<th></th>
<th>Defined according to verified cases</th>
<th>Defined by Sr level in blood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drownings (N = 45)</td>
<td>Non-drownings (N = 10)</td>
</tr>
<tr>
<td></td>
<td>Drownings (N = 41)</td>
<td>Non-drownings (N = 14)</td>
</tr>
<tr>
<td>L (g)</td>
<td>1717.50 (1345.75–1913.75)</td>
<td>1382.00 (1218.75–1936.75)</td>
</tr>
<tr>
<td></td>
<td>1717.50 (1412.25–1936.00)</td>
<td>1382.00 (1065.00–1737.75)</td>
</tr>
<tr>
<td>H (g)</td>
<td>390.00 (339.00–448.00)</td>
<td>533.00 (517.00–576.00)</td>
</tr>
<tr>
<td></td>
<td>387.00 (339.00–445.00)</td>
<td>533.00 (484.00–576.00)</td>
</tr>
<tr>
<td>LH (g/kg)</td>
<td>4.17 (3.21–5.61)</td>
<td>2.65 (2.12–2.77)</td>
</tr>
<tr>
<td></td>
<td>4.31 (3.274–5.80)</td>
<td>2.65 (2.14–3.09)</td>
</tr>
<tr>
<td>LB (g/kg)</td>
<td>22.21 (17.74–27.34)</td>
<td>15.45 (9.47–17.41)</td>
</tr>
<tr>
<td></td>
<td>23.31 (17.89–27.65)</td>
<td>15.32 (10.12–17.14)</td>
</tr>
<tr>
<td>B (kg)</td>
<td>73.00 (62.00–81.00)</td>
<td>87.00 (83.00–103.00)</td>
</tr>
<tr>
<td></td>
<td>73.50 (62.00–81.50)</td>
<td>87.00 (72.50–102.75)</td>
</tr>
</tbody>
</table>

Data represent the median and range (25–75% percentile). Group A is formed by all the bodies found in seawater. Group B is comprised of drownings ("verified non-drownings" excluded). Group C is comprised of drownings (individuals with Sr in left ventricle blood detected in group A (p = 0.034) (Table 5). This difference is accounted for by the fact that all deaths due to cardiac disease occurred during summer.

4. Discussion

Our study was designed to evaluate the possibility of establishing a lung weight value able to discriminate between seawater drownings and seawater "non-drownings".

We observed less overlap between cases of drownings and other forms of death in the sea with respect to the overlap reported by other authors [2], probably, because we used blood Sr to discriminate between drownings and non-drownings, such that several non-verified cases were considered as "non-drownings" based only on the lower blood Sr levels found.

Lung weight corrected for body weight (LB/B) appeared not to be dependent on the victim’s age (Tables 2–4) and was best at distinguishing between drownings versus non-drownings.
Table 4

Relationships between $L$, $H$, $L/H$, $L/B$, $B$ and age in group C of drownings created according to the Sr level in left ventricular blood

<table>
<thead>
<tr>
<th>Age groups</th>
<th>$L$ (g)</th>
<th>$H$ (g)</th>
<th>$L/H$ (g/g)</th>
<th>$L/B$ (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–40 years ($N=15$)</td>
<td>1717.50 (1412.25–1989.00)</td>
<td>328.00 (281.00–345.00)</td>
<td>5.21 (4.38–6.68)</td>
<td>22.21 (18.89–28.28)</td>
</tr>
<tr>
<td>40–60 years ($N=30$)</td>
<td>1832.50 (1592.50–2089.00)</td>
<td>397.00 (353.00–445.00)</td>
<td>4.31 (3.37–5.80)</td>
<td>23.94 (17.84–32.38)</td>
</tr>
<tr>
<td>&gt;60 years ($N=6$)</td>
<td>1501.00 (1217.50–1722.50)</td>
<td>468.00 (429.00–491.00)</td>
<td>3.09 (2.80–3.67)</td>
<td>18.60 (15.58–25.46)</td>
</tr>
</tbody>
</table>

Data represent the median and range (25–75% percentile). Group A is formed by all the bodies found in seawater. Group B is comprised of drownings (“verified non-drownings” excluded). Group C is comprised of drownings (individuals with Sr in left ventricle blood < 172 g/L excluded). $L$ is lung weight, $H$ heart weight and $B$ is body weight.

<table>
<thead>
<tr>
<th>$p$</th>
<th>$&lt; 0.05$ between 20–40 and 40–60 years old.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$p$</th>
<th>$&lt; 0.05$ between 20–40 and &gt;60 years old.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$p$</th>
<th>$&lt; 0.05$ between 40–60 and &gt;60 years old.</th>
</tr>
</thead>
</table>

Table 5

Relationships between a cold/warm water medium and lung weight increases

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Cold water</th>
<th>Warm water</th>
<th>Cold water</th>
<th>Warm water</th>
<th>Cold water</th>
<th>Warm water</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$ (g)</td>
<td></td>
<td>$L$ (g)</td>
<td></td>
<td>$L$ (g)</td>
<td></td>
</tr>
<tr>
<td>(N = 16)</td>
<td>(N = 39)</td>
<td>(N = 15)</td>
<td>(N = 30)</td>
<td>(N = 15)</td>
<td>(N = 26)</td>
</tr>
<tr>
<td>1801.00</td>
<td>1510.00</td>
<td>1798.00</td>
<td>1665.00</td>
<td>1798.00</td>
<td>1665.00</td>
</tr>
<tr>
<td>(1650.00–2023.75)</td>
<td>(1253.75–1848.75)</td>
<td>(1630.00–1943.00)</td>
<td>(1250.00–1888.00)</td>
<td>(1630.00–1943.00)</td>
<td>(1290.00–1958.50)</td>
</tr>
<tr>
<td>$L/H$ (g/g)</td>
<td>$L/B$ (g/kg)</td>
<td>$L/H$ (g/g)</td>
<td>$L/B$ (g/kg)</td>
<td>$L/H$ (g/g)</td>
<td>$L/B$ (g/kg)</td>
</tr>
<tr>
<td>4.30</td>
<td>20.60</td>
<td>4.30</td>
<td>20.60</td>
<td>4.30</td>
<td>20.60</td>
</tr>
</tbody>
</table>

Data represent the median and range (25–75% percentile). Group A is formed by all the bodies found in seawater. Group B is comprised of drownings (“verified non-drownings” excluded). Group C is comprised of drownings (individuals with Sr in left ventricle blood < 172 g/L excluded). $L$ is lung weight, $H$ heart weight and $B$ is body weight.

However, any selected $L/B$ cut-off value will fail to diagnose at least an approximate 12% of cases. In these non-diagnosed cases, we found high Sr blood levels indicating drowning, despite a small lung size suggesting non-drowning. Most of these cases corresponded to individuals falling to the water off rocks with no signs of pleural effusion. This discrepancy between Sr levels and lung weight could be the consequence of a period of unconsciousness in the water, during which there is no voluntary aspiratory lung activity, such that the lungs show a smaller size increase.

A further source of error is the difficulty in knowing which cases are “true” drownings or “non-drownings”. Thus, some natural deaths occurring in the water whereby the subject aspirates substantial water volumes can be easily misdiagnosed as true drownings. Neither classical autopsy findings nor diatoms can be used to make this distinction between drownings and non-drownings. The qualitative autopsy findings traditionally associated with drownings: acute emphysema, palpable grooves, subpleural hemorrhages (Paltauf’s sign), lung over-distension, froth around mouth, nostrils, etc., are recorded as evidence of fluid penetration into the airways as long as a minimum amount of liquid has been aspirated. These signs, however, were also observed in some of the verified cases of death in the water due to ischaemic cardiac failure (unpublished data).

The presence of diatoms in closed organs is yet another indicator of liquid aspiration by the lungs during the vital period. In our case, due to the incompatibility between routine analysis and the long time taken to perform acid/enzyme digestion of the whole organ, we currently use 10 g of tissue or 5 ml of blood to check for diatoms. In such conditions, the finding of diatoms depends more on their concentration in the water medium than on the amount of water aspirated during drowning. Hence, we were not surprised to find that the proportions of positive diatom results recorded in our tests (20–30%) were almost identical for the saltwater drownings (as determined by a blood Sr level >172 g/L) and the “non-drownings” (as determined by a blood Sr level <172 g/L) (unpublished data).

A cut-off value of around 17.5 g/kg for the $L/B$ index appeared to be the best at discriminating drownings from non-drownings, with only minor overlapping. However, using this cut-off, a small percentage, some 12.5% of all cases, were wrongly diagnosed. For practical purposes, it might be more valuable to select a cut-off value capable of ruling out deaths other than drowning rather than to discriminate between drownings and non-drownings, which cannot be fully achieved. Thus, all the non-drownings and 40% of the drownings examined here showed an $L/B$ value less than 19.5 g/kg. This cut-off value could, therefore, be used to indicate a death by...
drowning with some certainty. The use of a cut-off based on the
L/H index to distinguish drownings from non-drownings or
indicate deaths by drowning, seems to be more complicated
since this factor is affected by age. Moreover, the proportion of
wrong diagnoses using one or several L/H cut-offs in each age
group is higher than when the L/B index is used.

By stratifying the data according to whether the “drowning”
ocurred in the warmer or colder months (Table 5), we could
roughly observe the effects of the different water temperatures.
However, our main interest was to compare the different Sr or
lung weight index patterns. While no significant differences
were found in terms of the L, L/H and L/B indices between
drownings occurring in the cold and warm periods, it is
remarkable that in a previous report, we noted that left
ventricular blood Sr levels for drownings in the cold months
were significantly higher than levels recorded for drownings in
the warmer months [12]. Further, in apparent cases of “long
term immersion” during the colder months described in this
same paper, we found usual lung weight increases that seemed
to be inconsistent with the extremely high Sr levels determined
in left ventricular blood. These discrepancies related to
strontium absorption in the absence of considerable lung size
increase may be due to an extended period of unconsciousness
in some drownings occurring in cold water.

Despite the significant difference in L/B shown by
individuals considered to have drowned (>172 μg Sr/L of left
ventricular blood) compared to those considered as non-
drowned (<172 μg Sr/L of left ventricle blood) (Table 1), there
was no correlation between the two variables (Sr level and L/B).
In the group of non-verified non-drownings (<172 μg Sr/L),
poor correlation was indicated by the Spearman test ( ρ > 0.05).
The factors ischaemic cardiac failure, extrathoracic trauma,
oedema, etc., probably contribute more to the lung size increase
than fluid aspiration. The lack of correlation between lung
weight and blood Sr in the drownings group (>172 μg Sr/L)
could be attributable to different periods of underwater
unconsciousness.

In summary, our findings indicate that an L/B value higher
than 19.5 g/kg could be successfully used to diagnose deaths
due drowning in seawater, but that when the L/B index is lower
than this threshold, further markers of drownings, such as blood
Sr would be needed to establish the manner of death of a body
found in seawater.

References

Pathol. 6 (1985) 301–304.

Kamikodai, K. Tsuda, M.Q. Fujita, K. Nishi, T. Tsuji, H. Maeda, Lung–
heart weight ratio as a possible index of cardiopulmonary pathophysiology

Fujita, K. Nishi, T. Tsuji, H. Maeda, Postmortem lung weight in drown-
ings: a comparison with acute asphyxiation and cardiac death, Leg. Med. 5


[5] P. Saukko, B. Knight, Immersion deaths, in: Knight’s Forensic Pathology,

[6] P. Lunetta, J.H. Modell, A. Sajantila, What is the incidence and signifi-
cance of “Dry-Lungs” in bodies found in water, Am. J. Forensic Med.

centration related to the length of the agonal period in seawater drowning

[8] A.H. Idris, R.A. Berg, J. Bierens, C.M. Branche, A. Gabrielli,
S.A. Graves; A.J. Handley, R. Hoelle, P.T. Morley, L. Papa, P.E. Pepe, L.
Quan, D. Szilajman, J.G. Wigginton; J.H. Modell, Other Contributors: D.
Arkins, M. Gay, EMT-P; W. Kloeck, S. Timerman, Recommended guide-
lines for uniform reporting of data from drowning, Circulation 108 (2003)
2565–2568.


21.

adult autopsies: new tables for a Caucasoid population, Forensic Sci.

affecting the strontium absorption into blood in drownings, Forensic