Diagnosis of Drowning Literature Review – a work in progress

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If you have any related papers, or body-found-in-water or drowning cases you can share for our research please contact me. Thank you.

Putative Drowning Medium Substances in Circulatory System

If water from the drowning medium enters the lungs of a drowning person, the water and its constituents can pass from the alveoli to the blood in the venous pulmonary capillaries. From there these substances can enter the left side of the heart and the rest of the circulatory system as long as the heart continues to beat. If a body is dumped in water postmortem, water can still enter the lungs, but the water and its constituents cannot travel the circulatory system to organs, bone marrow, and other tissues because the heart is no longer functioning.

Hence, researchers have explored drowning diagnostic tools such as testing the difference between right and left cardiac blood for signs of hemodilution - a drowning victim's left heart blood could be more diluted than right heart blood, because inhaled water entering the pulmonary capillaries travels to the left side of the heart. Researchers have also examined blood and body tissues to see if they contain substances that were in the putative drowning medium. If concentrations of these substances are found, then the victim presumably had drowning as at least one cause of death. If these substances are not found in the blood or tissues, then either the person was dumped in water post mortem, or the substances in the drowning medium did not reach the blood or organs in concentrations high enough to be be detected by the testing methods used.

Examples of substances in blood that have been analyzed post mortem include diatoms[i],[ii],[iii], chloride[iv]; iron[v], magnesium[vi], strontium[vii],[viii], and atrial natriuretic peptide[ix].

Blood Strontium (BS)

Strontium-salts are found in most waters people drown in, including bathtub, canal, pond, lake, river, and seawater, and can reach the circulatory system as the water passes through the alveolocapillary membrane.

Fornes, Pepin, Heudes, & Lecomte (1998) used an atomic absorption spectrophotometer to obtain the blood strontium (BS) levels of 116 drowning victims and three control groups (23 living persons; 22 decedents with no asphyxia; 13 decedents with mechanical asphyxial deaths)[x]. BS concentrations in nondrowning cadaver blood are comparable to those found in living person blood, allowing the control group to be living person. The control group had low levels of BS with a narrow range. The drowning group had much higher levels of BS with a wide range. There was no overlap between in BS values between the drowning and control groups.

It is important to know the strontium concentration of the putative drowning medium to better understand the BS of the decedent, because there are widely varying strontium concentrations in different water. If the drowning medium has strontium-salt concentrations similar to BS concentrations found in nondrowned decedents, then there is little point of performing BS testing. In the above study the following strontium concentration medians and ranges were determined in microgram/L:

	Bathtub		Canal		Pond, Lake		River	
water	220	150-500	977	125-1035	400	2 cases	400	140-560
drowned subjects	124	80-280	210	80-670	120	100-160	127.5	80-320
non-drowned subjects	45	40-61	40	one case	no case		50	2 cases

Surrounding water and its dissolved strontium-salts could possibly increase BS concentrations of a "dumped" submerged body if the body's teguments[1] are putrefied or if exposed traumatic injury exists. In such cases the reliability of BS testing as a diagnostic index for drowning should be questioned.

Pulmonary Changes

Water is 800 times denser than the air our lungs evolved to inhale. Inhaled fluid can damage the lungs in a variety of ways such as tearing the 6-celled thick alveolar walls, destroying surfactant, and inhibiting gas exchange at the alveoli-pulmonary capillary interface. Pulmonary changes, also referred to as lesions, include pulmonary edema, emphysema aquosum, pulmonary congestion, alveolar hemorrhages, and alveolar macrophages.

Pulmonary edema

Pulmonary edema is an accumulation of fluid in the lung outside of the blood vessels, or simply said, "fluid in the lungs." This fluid can come from the inhaled drowning medium, from damage to alveoli that allows pulmonary capillary blood fluid to enter the air spaces, and from cardiac pump failure. Fluid accumulated in the lungs during a drowning or near-drowning incident can therefore come from both the drowning medium and the victim's own circulatory system.

Saltwater from the ocean has a higher concentration of salt than human blood, which means saltwater in the lungs can pull blood fluids into the alveolar spaces by the process of osmosis. Freshwater is less salty than blood, and can thus be pulled into the pulmonary capillaries by osmosis. Hence, the lungs of saltwater drowning victims may weigh more than the lungs of freshwater drowning victims, and the lungs of both types of victim may weigh more than the lungs of decedents who died from other causes. Generally a combined lung weight of more than 1,000 gm is considered heavy for an adult decedent.

Emphysema aquosum – alveolar wall disruption

Empysema aquosum is observed histologically as dilated alveoli with thin, elongated and sometimes ruptured walls[xi]. Davceva & Duma (2005) analyzed 29 autopsies of drowning victims and found that 94% of the nonputrefied cases presented with emphysema aquosum, also called Trocknenes Odem, drowning lungs, emphystema spumosum, or spongy emphysema because the lungs are like a wet sponge when cut and pressed[xii]. They described this lung lesion as:

> "Lungs are hypervoluminous, heavy, full of water, making crepitations,… on the autopsy table they do not collapse; the cutting surface seems 'dry' but after pressing it voluminous foamy whitey-pink and tiny bubbled contents burst forth."

Foamy liquid exits lungs with emphysema aquosum when pressure is applied. Sometimes sediment carried in the drowning medium can be seen in this foamy liquid, which of course should be documented and collected. Emphysema aquosum must be diagnosed microscopically. In comparison, when lungs with pulmonary edema are cut by a pathologist, liquid can be seen coming out of the lungs without applying pressure to the lungs.

If emphysema aquosum is found in the most peripheral parts of the lungs a check can be put in the "drowned" versus "dumped" column, since it would make sense that active respiratory movements would be required to achieve this lung condition. Keep in mind though, that this is not a diagnostic test, or even an index, rather it is one more variable to put in the hopper. Once all the variables are investigated count how many checks are in each column to see if there is a large enough difference to deem drowning as a cause of death.

Pulmonary congestion

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[1] Protective body covering of connective tissue and skin

Alveolar hemorrhages

Alveolar macrophages

Can pulmonary changes be used as an index for diagnosing drowning as a cause of death?

Zhu et al. (2003)[xiii] compared postmortem lung weights, and postmortem lung-heart weight ratios, from adult victims (20 years or older) of acute cardiac death (AMI) (n^2=75), mechanical asphyxiation (n=85: hanging, strangulation, smothering, aspiration, other), saltwater drowning (n=75), and freshwater drowning (n=67). Lung weight was defined as lung weight plus the amount of pleural effusion. The lung-heart ratio was examined to help control for individual subject differences in lung weights.

The main function of this study was to see if lung weights of drowning victims are significantly heavy enough to allow lung weights or lung-heart weight ratios to be an index for diagnosing drowning as a cause of death.

The results of the study were as follows:

1. The median value of total lung weight was highest in victims of saltwater drowning (1360 g $\pm$ 595 g), second highest in freshwater drowning (1323 g $\pm$ 446 g). AMI deaths ranked third (975 g $\pm$ 350 g) and mechanical asphyxial deaths had the lightest lungs (889 g $\pm$ 90.6 g).
2. AMI deaths had the heaviest hearts, with no significant differences between the other groups.
3. Lung weights were significantly positively correlated[3] to heart weights in all groups accept in salt-water drowning.
4. Lung-heart weight ratios were not dependent on postmortem interval times.
5. Lung-heart weight ratios had a tendency[4] to be higher in salt and freshwater drowning groups than in the AMI and asphyxial groups. This means that in the drowning victim groups lung weights were heavier as compared to their respective heart weights. The differences between heart and lung weights were not as great in the other groups. The AMI group had the smallest ratio, the smallest difference between lung and heart weigts, which makes sense since AMI hearts tend to be heavy.
6. The ratios of lung-heart rates were dependent on gender and age of the subjects as follows: The ratios of both drowning groups were significantly higher than the ratios for the AMI group. In males subjects the difference between both drowning groups was significantly higher than in the asphyxiation group. But, in female subjects, the difference between lung-heart ratios in drowning and asphyxia groups was not significant.
7. The difference in lung-heart ratios had a tendency to be higher in saltwater than in freshwater drowning groups. There was a significant difference between salt and fresh water groups in non-elderly males and in elderly females.

The gender and age differences described in results 6 and 7 are of interest and need to be explored with future research. Perhaps the manner in which victims drown could play a role in the weight of postmortem

[2] "n" is the number of subjects studied

[3] A positive correlation means as the values increase in one variable, they also increase in the other within individuals. In this case it means if a person had a heavy heart the lungs would also be heavy. A negative correlation occurs when the values increase in one variable and then decrease in the other variable within individuals. It is important to note that correlation does not mean causation.

[4] "Tendency" refers to a result that is not as strong as a "significant" result. For a result to be considered significant, the statistical p value must be less than .05 ($P<0.05$). A small P value shows a strong correlation between the variables examined, thus, the greater the relationship between the variables. A large P value occurs when there is little or no correlation, hence little or no relationship between the variables.

lungs. An accidental drowning of a person who becomes fatigued while attempting to swim in rough ocean water might result in heavier lungs than a person who is drowned more rapidly during a homicidal drowning in a bathtub or pool. Another avenue of exploration is that some decedents are given accidental drowning as the manner and cause of death, because they were found in water and no other cause of death was obvious, while in reality these decedents were the victims of homicide by manual asphyxiation alone or in conjunction with drowning.

This could perhaps help explain the gender differences between salt and freshwater. Male decedents are 4-5 times more likely to be found in water than are female decedents when the manner of death is accident, suicide, natural, or other[xiv]. But, when manner of death is deemed as homicide, females out-number males for bodies found in water[xv] . As is discussed throughout this Book, homicides with less-than-obvious causes of death may be too often diagnosed as drowning for cause of death by the process of exclusion, with accidental, suicidal, natural, or undetermined manner of death. Mechanical asphyxia can sometimes be more difficult to diagnose than other types of homicide such as stabbing, gunshot wound, or blunt force trauma, especially when there is a long postmortem interval. Female homicide victms are more likely to have asphyxia as the cause of death than are male homicide victims. Perpetrators of pure homicidal drowning or homicidal drowning in conjunction with mechanical asphyxia, would typically have access to freshwater (pools, bathtubs, lakes, rivers, ponds, creeks, culverts, drainage ditches, etc.) more frequently than salt water (oceans, a few lakes, and a few brackish rivers).

Fornes et al. (1998) evaluated the histomorphometry[5] of five sections of peripheral and central lung tissue from each of 46 drowned subjects, and compared them with mechanical asphyxia deaths and the three control groups described earlier. Pulmonary lesions were evaluated quantitiatively using a score from 0 to 3 with 1 being no lesion and 3 being extensive and widespread lesions. Measured parameters of alveolar walls included total area, total length, mean thickness. Also evaluated were number of alveolar spaces per unit area and mean area of alveolar spaces. Results included:

1. Edema was a nonspecific change
2. There was a tendency for the asphyxia group to have the highest levels of congestion.
3. The asphyxia group had significant alveolar wall differences when compared to the drowned group: the asphyxia group's wall thickness increased and length decreased, which may be due to the increased congestion
4. Nonputrefied drowned subjects had the lowest level of alveolar macrophages of all the groups, which may be due to the macrophages being washed out of the alveolar cavities.
5. Emphysema aquosum presented the most signicant difference between drowned and asphyxia groups as compared to nonasphyxia control groups, with the former having higher levels. The same was true for alveolar hemorrhage, but to a lesser degree. The lungs of drowned subjects had acute dilation of the alveoli.
6. Alveolar wall length was significantly reduced in the drowning group compared to the nonasphxia group. No other alveolar wall differences were significant.

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Blood Changes (Serum Markers)

Zhu et al (2003)[xvi] compared the left and right cardiac blood biochemistry of acute myocardial infarction (AMI) (n=23), freshwater drowning (n=11), and salt water drowning (n=15) decedents (ages 0-94 years) with postmortem intervals less than 48 hours. Results were as follows:

1. Blood urea nitrogen (BUN) and creatinine (CR) ratios between left and right heart blood, and in left heart blood alone, were significantly lower in both fresh and saltwater drowning groups than in the AMI group. There was no significant difference in the right cardiac blood between the three groups. This makes sense as it is the left cardiac blood that should be affected in drownings.
2. There was no significant difference in BUN and CR levels between the fresh and saltwater drowning groups.

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[5] The process of identifying the components of cells and tissues.

They also examined the levels of electrolytes and minerals, serum[6] chloride (Cl), calcium (Ca), sodium (Na), and magnesium (Mg) levels between the three groups to see if aspirated (inhaled) water disturbed the balances of electrolytes and minerals, or if there was hemodilution of the blood that leaves the lungs and enters the left heart chambers. Results included:

1. Levels of all of Cl, Ca, and Mg were significantly higher in both left and right cardiac blood in saltwater drowning as compared to the freshwater drowning and AMI groups.
2. The left-right cardiac blood ratio of Mg was significantly higher in saltwater than in the freshwater and AMI group.
3. The saltwater group had significantly higher serum Na levels in both cardiac bloods than the freshwater group.

To summarize these results, left-right cardiac BUN ratio was the most efficient marker for diagnosing drowning by diagnosing hemodilution of left heart blood. Left cardiac blood Mg was the best marker for differentiation between fresh and saltwater drowning. Saltwater had characteristic disturbance in electrolyte and mineral balances.

Zhu et al. (2005)[xvii] analyzed the pericardial fluid for urea nitrogen, creatinine, and uric acid in 409 forensic autopsies within 48 hours of deaths from blunt or sharp instruments, asphyxiation, drowning, fire, hyperthermia, hypothermia, methamphetamine, other poisoning, and delayed deaths form trauma and natural disease. Only the drowning fatalities demonstrated significantly lower levels for each of these markers.

Cardiac Troponin

When heart tissue dies from an myocardial infarction (MI) the dead cells release cardiac troponin T (cTn-T). Elevated serum SP-A demonstrates pulmonary alveolar damage.

Zhu et al. (2006)[xviii] examined cTnT levels in blood and pericardial fluid in 409 autopsies with survival times of less than 24 hours and postmortem intervals less than 48 hours. The cTnT levels were lower in the hypothermia and drowning deaths than in the blunt or sharp trauma, asphyxiation, hyperthermia, methamphetamine, abuse, carbon monoxide, MI, and cerebrovascular diseases.

1. MI had significantly higher cTn-T levels than either drowning group.
2. There was a mild elevation of cTn-T in freshwater drowning, which suggests secondary damage to heart muscle tissue. This was not found in saltwater drowning.
3. Freshwater drowning had a significant elevation of SP-A. Saltwater and AMI SP-A levels had overlaps.

They concluded that their findings “suggest that elevations in postmortem serum and pericardial cTnT levels depend on the severity of myocardial damage at the time of death.

What does this mean when determining cause of death of a body-found-in-water? If cardial troponin T levels are found to be high, then perhaps the death was cardiac related. This would not exclude drowning as a cause of death since myocardial damage could precipitate the inability of an immersed victim to survive in water. But, if the levels of cTnT are low and no other cause of death was discovered, then one more check can be put in the drowning column.

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[6] blood

[iii]

[iv] Gettler OA (1921)
[v] Canepa G (1963)
[vi] Moritz AR (1944)
[vii] Azparren J, de la Rosa I, Sancho M. (1994)
[viii] Fornes, P., Pépin, G., Druilhe, L., Huedes, D., Billaut, F., Lecomte, D., "Diagnosis of Drowning by a Combination of Computer-Assisted Morphometry of Lung Histological Changes and Blood Strontium Determination," *Proceedings, American Academy of Forensic Sciences, Annual Meeting,* Feb. 19-24, 1996, p. 136

[ix] Llorente JA, Villanueva E, Hernandez-Cueto C, Luna JD (1990)
[x] Fornes, P. et al. (1996), Ibid
[xi] Fornes, P. et al. (1996), Ibid.
[xii] Davceva N, Dum A. "Differential diagnostic elements in the determination of drowning." *Rom J Leg Med,* 13(1), 2005, p22-30.
[xiii] Zhu BL., Quan L., Ishida K., Oritani S., Li DR., Taniguchi M., Kamikodai Y., Tsuda K., Fujita MQ., Nishi K., Tsuji T., Maeda H. "Lung-hear weight ratio as a possible index of cardiopulmonary pathophysiology in drowning." *Legal Medicine*, 5, S295-297, (2003)
[xiv]

[xv]

[xvi] Zhu, B-L., Ishikawa, T., Michiue, T., Li, D-R., Zhao, D., Quan, L., Maida, H., "Evaluation of postmortem urea nitrogen, creatinine and uric acid levels in pericardial fluid in forensic autopsy," *Legal Medicine*, 7 (2005) 287-292

[xvii] Zhu BL., Ishikawa T., Michieue T., Li DR., Zhao D., Quan L., Maeda H. "Evaluation of postmortem urea nitrogen, creatine, and uric acid levels in pericardial fluid in forensic autopsy." *Legal Medicine* 7(2005), 287-292.
[xviii] Zhu BL., Ishikawa T., Michiue T., Li DR., Zhao D., Oritani S., Kamikodai Y., Tsuda K., Okazaki S., Maeda H. "Postmoretem cardiac troponin T levels in the blood and pericardial fluid. Part 1. Analysis with special regard to traumatic causes of death." *Legal Medicine* 8 (2006), 86-93.