Electrolyte Changes in Human Drowning Victims

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The sera of 118 consecutive drowning victims and 24 persons who died of other causes were drawn from both sides of the heart at autopsy and analyzed for electrolyte concentration and specific gravity. The data from humans correlate well with previous animal studies and indicate that approximately 85 per cent of both fresh- and sea-water drowning victims aspirate 10 ml of fluid or less per pound body weight. It is unlikely, therefore, that most drowning victims die acutely of electrolyte imbalance and/or ventricular fibrillation. Death is more likely to be secondary to asphyxia. Results of the study also indicate that neither the chloride test nor the specific gravity of serum can be relied upon to establish a diagnosis of death by drowning.

In 1921, Gettler described the chloride test for diagnosis of death by drowning.[1] Since then, others have investigated the changes which occur in serum electrolyte concentrations during drowning by total immersion.[2] In these studies profound electrolyte changes have been reported. Studies in which controlled quantities of fluid were aspirated[3, 4, 5] and experience in treating human near-drowning victims[6-9] suggest that such profound changes are rare and seldom are the primary cause of death. This study was designed to document the magnitude and incidence of electrolyte changes in human drowning victims.

Methods

One hundred eighteen consecutive recent drowning victims were studied. Excluded from this study were victims who had been in the water for an indeterminate time and whose bodies showed signs of decomposition. Also excluded were victims with severe coronary artery disease such that the question of an initiating or concomitant heart attack could be raised. The diagnosis of drowning was based on a combination of the circumstances surrounding the terminal episode with autopsy findings of variable amounts of froth in the airway, pulmonary congestion and edema, and water in the stomach and sphenoid sinus.

The following were recorded: age, interval between drowning and the time the body was delivered to the Medical Examiner's Office and refrigerated, and the time between drowning and autopsy. At autopsy, blood was drawn from the right and left ventricles using individual sterile 13-gauge needles and 50-ml syringes. The blood was centrifuged immediately, the serum removed, and serum specific gravity determined. The sample was then frozen for future serum electrolyte analyses. Although electrolyte concentrations of all samples were determined, specific gravities of sera of persons whose blood was grossly hemolyzed are not reported.

The serum was defrosted and analyzed for sodium, potassium and chloride. Sodium and potassium were determined on a Coleman flame photometer using a commercial preparation as a standard. Chloride concentration was determined with the Buchler-Cotlove chloridometer. Differences between the left and right heart samples (L-R) were calculated. Chloride values were converted to mg/100 ml of sodium chloride in order to apply Gettler's test, which assumes that if the concentration of sodium chloride is at least 25 mg/100 ml (4.3 mEq/l) greater in whole blood from the left heart than in whole blood from the right heart, the victim drowned in sea water; if at least 25 mg/100 ml less in the left he drowned in fresh water; if there is less than a 25 mg/100 ml difference between samples from the

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left and right ventricles the patient did not drown.[1] [*] These studies were also performed on a control group of 24 persons who died acutely of causes other than drowning with no evidence of chronic illness.

Data were entered on IBM data cards. Means and standard deviations were calculated. Tests for significance of differences between comparable data of the three groups were sought by Student's t test with the aid of a digital computer.[11]

Results

A total of 74 victims who drowned in fresh water pools, rock pits or canals (FW), 44 seawater victims (SW) retrieved from Atlantic Ocean beaches, and 24 persons who died of causes other than drowning (C) were studied. Although there was no difference between the average ages of the controls and the SW drowning victims ($45.5 \pm$ SE 5.2 years and $48.9 \pm$ SE 4.2 years, respectively), the average age of FW victims was significantly less than the other groups ($27.7 \pm$ SE 2.9 years) ($P < 0.01$). The average intervals between drowning, or death, and refrigeration were $263 \pm$ SE 39 minutes, $238 \pm$ SE 49 minutes, and $160 \pm$ SE 21 minutes for the FW, SW and control groups, respectively. The average intervals between death and autopsy were: FW, $858 \pm$ SE 55 minutes; SW, $741 \pm$ SE 91 minutes; C, $585 \pm$ SE 92 minutes.

Electrolyte and specific gravity data are shown in table 1 (C), table 2 (SW), and table 3 (FW). The mean values for serum chloride, sodium, potassium and specific gravity of samples taken from the left ventricle are listed and compared for significant differences between groups in table 4.

Specific gravity of serum from the left ventricle was lower than that from the right in most patients, regardless of the cause of death. In the control group, specific gravity was lower in the left ventricle than in the right in 16 victims, higher in one, and equal on both sides in five. In the SW group, specific gravity was lower in the left ventricle than in the right in 30 victims, higher in seven, and both sides were equal in one. Victims of FW drowning had lower specific gravity in the left ventricle in 54 cases, higher values in four, and equal values in both ventricles in one.

When differences in chloride concentrations of sera taken from the left and right ventricles were compared according to Gettler's criteria, errors in diagnosis were found in 42 per cent of controls, 16 per cent of SW victims, and 90 per cent of FW victims (table 5).

A frequency distribution of serum chloride and sodium concentrations found in the left and right ventricles is listed in table 6. A serum chloride concentration of 100–105 mEq/l was assumed to be normal. The incidences of values within 20 mEq/l of normal, at least 20 mEq/l less than normal, and two groups greater than normal (20–30 mEq/l and >30 mEq/l) are listed for correlation with previous studies in animals. A value of 140 mEq/l sodium was arbitrarily set as normal and the incidences of values in ranges comparable to those reported for chloride are listed.

Regressions of both the serum chloride concentration in the left ventricle and the difference in serum chloride concentration between the left and right ventricles were made on the computer, based on patient age, time from death to refrigeration, and time from death to autopsy, for correlation between factors.[12] The only significant regressions found were those of the concentration of serum chloride in the left ventricle on length of time from death to autopsy in the control group ($r = -0.627$; $P = 0.0001$) and in the SW group ($r = -0.340$; $P < 0.05$); but not in the FW group ($r = -0.174$; $P > 0.10$). These negative regressions would allow for a postmortem fall of left ventricular chloride concentration of 1.7 mEq/l per hour in the control group and 0.15 mEq/l per hour in the SW group.

Discussion

Heretofore, electrolyte changes secondary to aspiration of hypo- or hypertonic fluid have been emphasized as a major cause of death from drowning.[2, 13] In addition, diagnostic tests based on serum chloride concentrations [1, 13] and specific gravity [14, 15] have been proposed. The results of this study together

[*] Since erythrocyte chloride concentration (Cl^-) is normally 80 per cent of serum levels,[10] whole blood Cl^- is less than serum Cl^-. Gettler's criterion of a 25 mg/100 ml deviation in whole blood becomes 29 mg/100 ml when serum is used.

TABLE 1. Serum Electrolyte and Specific Gravity Data from 24 Persons Who Died Acutely of Causes Other Than Drowning*

	Sample Size	Mean	SD	SE	Minimum	Maximum
Cl,mEq/l						
(L)	24	93.0	8.7	1.8	79.0	119.0
(R)	24	88.6	7.8	1.6	74.0	111.0
(L-R)	24	4.4	4.1	0.8	−4.0	10.0
Na,mEq/l						
(L)	24	135.2	9.9	2.0	111.0	149.0
(R)	24	133.2	10.7	2.2	108.0	148.0
(L-R)	24	2.0	7.2	1.5	−20.0	18.0
K,mEq/l						
(L)	24	18.6	9.1	1.9	7.5	36.2
(R)	24	21.3	9.1	1.9	5.3	39.5
(L-R)	24	−2.8	3.8	0.8	−12.7	2.5
Specific gravity						
(L)	22	1.0309	0.0046	0.0010	1.0229	1.0395
(R)	22	1.0327	0.0039	0.0008	1.0272	1.0395
(L-R)	22	−0.0017	0.0018	0.0004	−0.0058	0.0002

* Samples were drawn from the left ventricle (L) and right ventricle (R). Differences in electrolyte concentration and specific gravity between the two sides of the heart are listed (L-R).

TABLE 2. Serum Electrolyte and Specific Gravity Data from 44 Persons Who Died of SW Drowning*

	Sample Size	Mean	SD	SE	Minimum	Maximum
Cl,mEq/l						
(L)	44	120.5	16.8	2.5	86.0	171.0
(R)	44	103.6	10.8	1.6	79.0	137.0
(L-R)	44	16.5	13.8	2.1	−20.0	55.0
Na,mEq/l						
(L)	44	149.8	12.5	1.9	121.0	198.0
(R)	44	143.9	10.3	1.6	106.9	163.0
(L-R)	44	5.8	9.2	1.4	−15.0	37.0
K,mEq/l						
(L)	44	16.1	6.6	1.0	7.0	29.6
(R)	44	18.6	6.8	1.0	9.3	37.0
(L-R)	44	−2.5	3.6	0.5	−11.6	7.8
Specific gravity						
(L)	39	1.0307	0.0037	0.0006	1.0225	1.0375
(R)	39	1.0336	0.0038	0.0006	1.0230	1.0422
(L-R)	39	−0.0029	0.0042	0.0007	−0.0187	0.0050

* Samples were drawn from the left ventricle (L) and right ventricle (R). Differences in electrolyte concentration and specific gravity between the two sides of the heart are listed (L-R).

with prior results from this laboratory[3, 5, 7] suggest that profound changes in serum sodium and chloride concentrations are rare in drowning victims. These results also shed considerable doubt on the reliability of diagnostic tests based on electrolyte changes.

ELECTROLYTE CHANGES IN FW DROWNING VICTIMS

While the mean concentration of serum sodium in the left ventricle was significantly less in the FW drowning victims than in the con-

TABLE 3. Serum Electrolyte and Specific Gravity Data from 74 Persons Who Died of FW Drowning*

	Sample Size	Mean	SD	SE	Minimum	Maximum
Cl,mEq/l						
(L)	74	89.0	11.4	1.3	48.0	131.0
(R)	74	86.2	8.3	1.0	65.0	103.0
(L-R)	74	2.8	8.1	0.9	−40.0	31.0
Na,mEq/l						
(L)	74	127.5	11.5	1.3	97.0	162.0
(R)	74	129.2	9.6	1.1	89.0	157.0
(L-R)	74	−1.7	8.4	1.0	−40.0	16.0
K,mEq/l						
(L)	73	18.2	7.4	0.9	5.0	53.0
(R)	74	21.6	8.2	1.0	8.3	62.9
(L-R)	73	−3.5	4.2	0.5	−17.6	5.3
Specific gravity						
(L)	59	1.0280	0.0040	0.0005	1.0205	1.0370
(R)	59	1.0314	0.0043	0.0006	1.0219	1.0438
(L-R)	59	−0.0032	0.0032	0.0004	−0.0185	0.0045

* Samples were drawn from the left ventricle (L) and right ventricle (R). Differences in electrolyte concentration and specific gravity between the two sides of the heart are listed (L-R).

trols, mean chloride and potassium concentrations in the two groups were not different. In only ten of 74 FW drowning victims (14 per cent) were the concentrations of serum chloride in the left ventricle less than 80 mEq/l; in only 12 (16 per cent) were the serum sodium concentrations less than 120 mEq/l. These values may be correlated with experimental data from animals in which aspiration of 10 ml per pound or less of FW produced sodium and chloride values less than 20 mEq/l below normal three minutes after aspiration, and aspiration of 20 ml per pound produced values more than 20 mEq/l below normal.[4] While the sodium and potassium concentrations of dog and human erythrocytes are different, the concentrations of chloride are similar in the two species. Serum concentrations of all three electrolytes in the dog are almost identical to values in humans.[10] It is reasonable, therefore, to use the chloride values for the most reliable comparison. Of further note is that sodium changes after aspiration of 10 ml of FW per pound body weight in rabbits are comparable to those found in dogs.[16] Since erythrocytes of rabbits and hu-

TABLE 4. Means and Standard Deviations of Serum Electrolyte Concentrations and Specific Gravities of Samples Obtained from the Left Ventricles of Victims of FW Drowning, SW Drowning, or Other Causes (Control)

	Fresh Water Victims (74)	FW vs. Control P value	Controls (24)	Control vs. SW P value	Sea Water Victims (44)	FW vs. SW P value
Cl,mEq/l	89 ± 11.4	*	93 ± 8.7	<0.001	120 ± 16.8	<0.001
Na,mEq/l	128 ± 11.5	<0.01	135 ± 9.9	<0.001	150 ± 12.5	<0.001
K,mEq/l	18.2 ± 7.4	*	18.6 ± 9.1	*	16.1 ± 6.6	*
Specific gravity	1.0280 ± 0.0040	<0.01	1.0309 ± 0.0046	*	1.0307 ± 0.0037	<0.01

* No significant difference between groups, $P > 0.10$.

TABLE 5. Differences in Concentrations of Serum Chloride in the Left and Right Ventricles Calculated as mg/100 ml NaCl*

	Total Number of Victims	Diagnosis Predicted by Gettler's Criteria		
		Fresh-water Drowning	Not Drowned	Sea-water Drowning
Group 1 Controls	24	0	14	10
Group 2 Sea-water victims	44	2	5	37
Group 3 Fresh-water victims	74	7	37	30

* Cause of death compared with the expected cause of death according to Gettler's criteria.

mans have similar levels of sodium and potassium,[10] this further supports the rationale for comparison.

When dogs aspirate 10 ml or less of distilled water per pound body weight they do not die of ventricular fibrillation.[3, 4, 17] When at least 20 ml of fluid per pound is aspirated, however, fibrillation occurs in 80 per cent of animals, at a mean time of 3.25 minutes following aspiration.[4] If the animal data can be extrapolated to humans, approximately 85 per cent of human FW drowning victims aspirate less than 10 ml of fluid per pound and, therefore, probably do not die acutely of electrolyte imbalance and/or ventricular fibrillation. A more likely cause of death is asphyxia.[3, 4, 7] If these victims had been rescued and resuscitated, it is unlikely that abnormal electrolyte values would have been demonstrable, since electrolyte homeostasis is reached rapidly in both humans and animals that survive FW near drowning.[3, 7]

There are two reasons for selecting left ventricular blood for comparison between animals and humans. First, in the animal experiments, samples were drawn from the arch of the aorta, thus reflecting electrolyte changes distal to the lung. Second, if there is a rapid transfer of fluid and electrolytes across the alveolar–capillary membrane, the resultant changes probably would have appeared distal rather than proximal to the lungs. We have compared the electrolyte values at autopsy in humans with those seen three minutes after aspiration in dogs. In dogs after drowning in FW the concentration of serum chloride progressively decreases with time.[13] If this also occurs in humans, it would exaggerate the electrolyte changes found and further strengthen the conclusion that less than 15 per cent of victims aspirated 20 ml or more of FW per pound.

ELECTROLYTE CHANGES IN SW DROWNING VICTIMS

The mean concentrations of serum chloride and sodium in the left ventricles of sea-water drowning victims were significantly higher than those of either the controls or the fresh-water victims. Potassium concentrations were

TABLE 6. Frequency Distribution of Concentration of Serum Sodium and Chloride from the Left (LV) and Right (RV) Ventricles of FW and SW Drowning Victims and Persons Who Died from Other Causes

	Total No. Victims		Serum Chloride, mEq/l				Serum Sodium, mEq/l			
			≤79	80–125	126–135	>135	≤119	120–160	161–170	>170
Group 1 Controls	24	LV	1	23	0	0	1	23	0	0
		RV	4	20	0	0	3	21	0	0
Group 2 Sea-water victims	44	LV	0	26	11	7	0	39	4	1
		RV	1	42	0	1	1	41	2	0
Group 3 Fresh-water victims	74	LV	10	63	1*	0	12	61	1*	0
		RV	16	58	0	0	12	62	0	0

* Body recovered from canal near entrance to bay; position of tide unknown.

comparable in all groups, however. When the frequency distribution of serum chloride samples from the left ventricle were analyzed, 59 per cent of victims had chloride values within 20 mEq/l of normal. An additional 25 per cent had values between 21 and 30 mEq/l above normal. These data can be compared with results of animal experiments in which three minutes after aspiration of 5 ml of sea water per pound body weight the average increase in serum chloride concentration in the aorta was less than 20 mEq/l. When 10 ml per pound of SW was aspirated, the mean increase was less than 30 mEq/l. From these data, it appears that 59 per cent of SW drowning victims aspirate 5 ml or less of SW per pound body weight, an additional 25 per cent aspirate between 5 and 10 ml of SW per pound body weight, and only 16 per cent aspirate more than 10 ml of SW per pound body weight.

These data compare well with the findings in the FW drowning victims where, based on chloride determinations in the left ventricle, 14 per cent were estimated to have aspirated more than 10 ml of water per pound body weight. The serum sodium data in the SW drowning victims indicate that the majority of patients aspirated less than 5 ml of water per pound body weight. It has been shown previously in both animal experiments and observations in human near-drowning victims, however, that following SW drowning changes in serum chloride persist longer than changes in sodium.[5, 7] It seems reasonable, therefore, to assume that the serum chloride levels would be more reliable in this situation.

Diagnostic Tests for Drowning

The figures in table 5 emphasize the poor reliability of Gettler's chloride test for death by drowning. While his criteria would have resulted in only 16 per cent wrong diagnoses in this series of SW drowning victims, 42 per cent of controls and 90 per cent of FW victims would have been diagnosed incorrectly. Gettler proposed his test on the basis of findings in only three FW drowning victims (only two of them had been suspected to have died from drowning) and 16 SW victims.[1] Moritz questioned the reliability of this test more than 20 years ago, and emphasized the importance of performing an autopsy early, because the chloride concentrations in left and right heart blood changed with time, thus making differences more difficult to detect.[13] In the present study a negative correlation between increasing time from death to autopsy and concentration of serum chloride in the left ventricle was found in persons who had died from causes other than drowning and in SW drowning victims; however, the correlation in the FW drowning victims was not significant. If the chloride test were consistently reliable in diagnosing FW drowning when autopsy was performed immediately after death, we would expect to see a correlation between the chloride concentration of either the left heart blood or the difference between left and right heart blood and time. Such a correlation was not seen. Similar conclusions regarding the unreliability of this test have been drawn by other authors.[14]

In 1953, Durlacher, Freimuth and Swann suggested that a more accurate test for drowning could be obtained by measuring specific gravity of plasma in the right and left sides of the heart. They reported that if the specific gravity is lower in the left heart than the right, the cause of death is drowning, either FW or SW, and if the specific gravity is greater in the left than in the right, the patient died of some other cause.[14] Subsequently, however, they found 45 per cent of non-drowning victims had lower specific gravities on the left than on the right.[15] In our study the specific gravity of plasma was less in the left ventricle than in the right in 91 per cent of FW drowning victims, 79 per cent of SW drowning victims, and 75 per cent of persons who died of other causes. Thus, it is not possible to separate the drowning victims from the controls by this criterion. An important difference between their second study and ours was that they corrected the specific gravity for hemolysis. This was not done by us; however, the specific gravity was not determined for persons with gross hemolysis.

From the results of this study it may be concluded that if human and animal data can be compared, the majority of human drowning victims (approximately 85 per cent) aspirate

10 ml or less of fluid per pound body weight. It is unlikely, therefore, that most drowning victims die acutely of electrolyte imbalance and/or ventricular fibrillation. More likely, their deaths are due to acute asphyxia, and, if rescued, promptly resuscitated, and given intensive pulmonary therapy, they would stand a reasonable chance for survival. Diagnosis of death by drowning based on differences in specific gravity or chloride concentration of serum samples taken from the left and right ventricles at autopsy is not reliable.

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