Physiologic Effects of Near Drowning with Chlorinated Fresh Water, Distilled Water and Isotonic Saline

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The clinical picture and biochemical changes reported in human victims of near-drowning is considerably different from those reported in dogs subsequent to total immersion in fresh water. To gain further insight into this apparent discrepancy and to study the differences in the pathophysiological response of animals to drowning in chlorinated fresh water compared to unchlorinated fresh water and isotonic saline solution, a group of experiments was undertaken.

The changes in cardiovascular dynamics, blood constituents and serum electrolytes observed in this study were transient, frequently limited to the arterial samples; these spontaneously reverted to normal in the thirteen animals who survived the experiment. Ten to sixty minutes post-immersion the three groups studied were indistinguishable. Conversely, acute asphyxiation with arterial hypoxemia and metabolic acidosis which persisted throughout the experiment was seen in all animals. The presence of chlorine in distilled water did not significantly alter the response to aspiration.

DEATH from drowning usually results from a combination of respiratory and circulatory disturbances secondary to the aspiration of water. In 1947, Swann and his associates¹ published the first of a series of reports on the biochemical changes in dogs following total immersion in fresh and sea water. After fresh water aspiration, the dogs developed acidosis, hypoxia, hypercarbia, a decreased hemoglobin content, and a rapid hypervolemia as measured by blood specific gravity. In addition, these investigators observed hypernatremia, hypochloremia, hyperkalemia and a transient hypertension, followed by profound hypotension and frequently ventricular fibrillation within moments of immersion.² In 1961, Redding et al.³ found it difficult to resuscitate dogs who aspirated fresh water since ventricular fibrillation occurred within three minutes of instituting artificial ventilation. Closed-chest cardiac massage and electrical defibrillation were followed by resumption of a spontaneous heartbeat and blood pressure. Intermittent positive pressure ventilation was discontinued after one hour and all animals died within a 24-hour period, with evidence of massive hemolysis and myocardial failure. It would appear from these experiments that the consequences of rapid absorption of water into the circulatory system and resultant changes in blood constituents and electrolytes are of primary importance in death from fresh water drowning and the respiratory difficulties of secondary importance.

Following these excellent experiments, other investigators applied the results obtained in animals to man and have advocated methods of resuscitation stressing the circulatory problems.⁴, ⁵, ⁶

In a review of case reports compiled by Fuller,⁷ however, the course of human beings who have suffered a fresh water near-drowning episode does not follow that predicted by Swann’s laboratory data. The major findings in these patients is pulmonary edema rather than intravascular complications. Most fre-

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quently people who aspirate fresh water show normal serum electrolyte concentrations and frequently demonstrate a high hemoglobin and high hematocrit rather than the low hemoglobin, low hematocrit, and abnormal serum electrolytes as predicted from animal data. Assuming that species variation is not a factor, these differences may be related to the chlorine in fresh water pools or the debris in lakes which may alter the rate of fluid absorption.8 Other more likely possibilities are: (1) human near-drowning victims aspirate smaller quantities of water than obtain in total immersion animal studies; or (2) the changes in concentration of blood elements and serum electrolytes secondary to fresh water aspiration rapidly revert to normal during recovery.

To gain further understanding of this apparent discrepancy between dog and man, and to study the differences in the response of animals to near-drowning in chlorinated fresh water compared to unchlorinated fresh water, the following experiments were undertaken.

Procedure

Fifteen mongrel dogs weighing 25 to 50 pounds and in apparent good physical condition were divided into groups of five according to the type of water aspirated.

Group I: Chlorinated. Distilled water to which five parts per million of chlorine (trichloro-s-triazinetrione) was added on the day of the experiment.

Group II: Distilled. Unchlorinated distilled water.

Group III: Saline Control. Isotonic saline solution (0.9 N).

After a 15 gauge Rochester needle was inserted into a vein of the foreleg, 50 mg. increments of 2½ per cent sodium thiopental were given intravenously to produce basal narcosis (i.e., cessation of spontaneous movement; respiration and lid reflex remained active). The trachea was intubated under direct vision, the endotracheal tube cuff inflated and the animal permitted to breathe spontaneously.

Both femoral arteries and veins were cannulated with siliconized polyethylene tubing (inside diameter, 0.068 inch). The arterial catheters were threaded to the proximal portion of the descending aorta and the venous catheters into the inferior vena cava near the right atrium. Position of catheters was subsequently confirmed at autopsy. The catheters on the left side were connected via Stat-ham strain gauges to a multichannel photographic recorder for monitoring of arterial and venous pressures. The catheters on the right were connected to a triple stopcock assembly for sampling of blood. Lead 2 of the electrocardiogram was recorded continuously.

Twenty minutes prior to immersion, radioactive iodinated serum albumin (RISA) was injected intravenously and the needle flushed with 5 per cent dextrose in water. Five to ten minutes preimmersion, respiratory minute volume was measured in triplicate with a Wright Ventilometer connected to the endotracheal tube. Respiratory rate was counted and the average tidal volume calculated.

Four minutes prior to immersion, arterial blood samples were drawn anaerobically into heparinized, greased syringes and the pH measured in the AME-1 Astrup Micro Apparatus. The PCO₂ and base excess were calculated from the Sigggaard-Andersen nomogram.9 Arterial PO₂ was also measured on the Astrup Apparatus using a direct reading Clark type oxygen electrode.10 Arterial and venous bloods were drawn simultaneously at this time and transferred immediately to sets of heparinized test tubes for whole blood studies and clean test tubes for clot formation for serum analysis. Care was taken to avoid stasis of blood in catheters by removing 5 ml. of blood and discarding immediately before samples were withdrawn and to avoid hemolysis. Heparinized blood was analyzed for total hemoglobin by the cyanmethemoglobin method and for hematocrit using the Guest-Weichselbaum micro-capillary centrifuge. The blood was then centrifuged, the plasma removed and analyzed for hemoglobin by a modified version of the Bing and Baker technique.11 Serum studies included determination of sodium, potassium and calcium on the Coleman flame photometer using a commercial serum preparation as a control standard. Serum chloride analysis was performed on the Buchler-Cotlove Chloridometer. Venous blood was used for blood volume studies utilizing the RISA technique with a Picker Hemoliter Counter.

Thirty seconds prior to immersion the endotracheal tube was connected via a Y_adapter
to a water reservoir and breathing bypass (fig. 1). At zero time the bypass was occluded and each dog allowed to aspirate 10 ml. of water per pound of body weight. After aspiration the animal was again allowed to breathe room air through the emptied water reservoir. As soon as water cleared, the reservoir was disconnected from the endotracheal tube and ventilatory studies were performed. One, 3, 5, 10, 30, and 60 minutes after the onset of immersion, arterial and venous blood determinations were repeated. When the 60-minute postimmersion determinations were completed, all surviving animals were sacrificed with an over-dose of intravenous sodium thiopental and autopsy performed. Gross pathology of the tracheobronchial tree, lungs, and heart was noted.

Results

All data reported represent average values for each group of 5 animals. When an animal expired prior to the termination of the experiment data were included until time of death. Average control values of weight, tidal volume, total volume of fluid aspirated, and fluid/tidal volume ratio for each group are shown in table 1. Thirteen of the 15 animals survived the 60-minute experiment. One dog died five minutes after chlorinated water aspiration and one seven minutes after saline aspiration. In both, the immediate cause of death appeared to be apnea.

Cardiovascular Changes. A decline in systolic blood pressure was seen within 14 seconds of immersion in all 15 animals studied. This was immediately followed by hypotension before the blood pressure returned to normal levels (table 2). Both the degree and duration of hypotension were more severe in the combined fresh water group than in the saline control \( P = < 0.05 \); however, the duration of hypotension that followed was equivalent in both groups \( P = > 0.9 \). A significant difference in the degree of hypotension was also noted between groups I and II \( P = < 0.05 \).

Venous pressure rose in all animals immediately following aspiration and gradually returned to normal when the arterial pressure stabilized. A transient decrease in pulse rate below 100 per minute was noted within 15 seconds of immersion in all animals who aspirated fresh water and in one after saline aspiration. A similar decrease was seen within

* Two sample Student's t test.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Animals</th>
<th>Average Weight (lbs.)</th>
<th>Volume Fluid Aspirated (ml.)</th>
<th>Control Tidal Volume (ml.)</th>
<th>Fluid/Tidal Volume ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Chlorinated</td>
<td>5</td>
<td>36</td>
<td>360</td>
<td>182</td>
<td>1.98</td>
</tr>
<tr>
<td>II Distilled</td>
<td>5</td>
<td>43</td>
<td>430</td>
<td>186</td>
<td>2.31</td>
</tr>
<tr>
<td>III Saline</td>
<td>5</td>
<td>37</td>
<td>370</td>
<td>209</td>
<td>1.77</td>
</tr>
<tr>
<td>All groups combined</td>
<td>15</td>
<td>30</td>
<td>390</td>
<td>192</td>
<td>2.03</td>
</tr>
</tbody>
</table>
one minute in three additional animals in the saline group. Bigeminy appeared in 9 of 15 (group I; 3; group II; 2; group III; 4). An elevated T wave appeared in three of the five animals in both of the distilled water groups (with and without chlorine).

**Ventilatory Response.** Apnea occurred within nine seconds of aspiration (mean 4 seconds) in 14 of the 15 animals studied and persisted for 10 to 39 seconds. Average duration of the initial apneic episode was 25 seconds in group I, 22 seconds in group II, and 19 seconds in group III. Although all surviving animals were hyperventilating at the conclusion of the experiment, this was most marked in the saline controls ($P = <0.05$) (table 3).

**Blood Gas and Acid-Base Studies.** The average values for arterial pH, $P_{O_2}$, $P_{CO_2}$, and base excess for each of the three groups studied are shown in figure 2. All groups show the same trends. The pH reached its lowest value five minutes after onset of immersion and although a gradual return toward normal was seen, the average pH for the three groups was still 7.30 at the end of the 60-minute test period. The $P_{O_2}$ dropped sharply to a mean of approximately 40 mm. of mercury one minute following aspiration in all groups and remained below 50 mm. of mercury throughout the remainder of the experiment. Base excess reached its lowest value 10 minutes after onset of immersion. There was an immediate but transient rise in $P_{CO_2}$ in all groups which reached a peak five minutes postimmersion.

**Hemoglobin, Hematocrit, and Blood Volume.** Except for a transient fall in arterial hemoglobin concentration one minute after onset of immersion in both distilled water groups, the average hemoglobin values for all three groups remained essentially normal and indistinguishable (range 12.3 to 14.0 g./100 ml.). Venous hemoglobin determinations did not demonstrate this initial decline in groups I and II but rather, remained normal to moderately elevated throughout the experiment. Presumably this was because of the rapid entry of water into the arterial system which is subsequently redistributed before venous return. The hematocrit remained normal to 0.4.

### Table 2: Systolic Blood Pressure Changes Subsequent to Aspiration of Chlorinated Distilled Water, Unchlorinated Distilled Water, and Physiological Saline Solution (10 ml./pound)

<table>
<thead>
<tr>
<th>Group</th>
<th>Maximum Decline in Systolic Blood Pressure in mm. Hg</th>
<th>Duration of Hypotension in Seconds</th>
<th>Duration of Hypertension in Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
<td>Average</td>
</tr>
<tr>
<td>I Chlorinated</td>
<td>43*</td>
<td>30–56</td>
<td>22</td>
</tr>
<tr>
<td>II Distilled</td>
<td>77*</td>
<td>32–56</td>
<td>45</td>
</tr>
<tr>
<td>III Saline</td>
<td>31*</td>
<td>25–40</td>
<td>5*</td>
</tr>
</tbody>
</table>

* $P = <0.05$

### Table 3: Summary of Respiratory Response Prior to and Sixty Minutes Following Onset of Immersion

<table>
<thead>
<tr>
<th>Time</th>
<th>Group</th>
<th>Respiratory Rate per Minute</th>
<th>Minute Volume (liters/minute)</th>
<th>Tidal Volume (ml.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Prior to immersion</td>
<td>I</td>
<td>20–35</td>
<td>25</td>
<td>2.6–6.3</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>23–37</td>
<td>42</td>
<td>4.5–11.5</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>17–40</td>
<td>26</td>
<td>2.5–8.6</td>
</tr>
<tr>
<td>60 min. post-</td>
<td>I</td>
<td>47–104</td>
<td>74</td>
<td>9.2–16.4</td>
</tr>
<tr>
<td>immersion</td>
<td>II</td>
<td>64–128</td>
<td>90</td>
<td>10.0–22.3</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>118–160</td>
<td>137*</td>
<td>17.2–30.2</td>
</tr>
</tbody>
</table>

* $P = <0.05$. 
slightly elevated in all three groups (range 37 to 45 volumes per cent). The blood volume demonstrated an initial sharp rise to 135 and 132 per cent of the pre-aspiration volume three minutes postimmersion in the chlorinated and unchlorinated distilled groups, respectively. These figures are not significantly different \( (P > 0.2) \). The saline controls, however, showed a more gradual rise in blood volume approaching the other groups toward the end of the experiment \( (P < 0.05 \text{ at one, three, and five minutes}) \). Sixty minutes postimmersion, blood volumes were 129, 128, and 124 per cent of their pre-aspiration value in groups I, II, and III, respectively (fig. 3).

Gross hemolysis was observed in all animals that aspired unchlorinated distilled water, four of five animals in the chlorinated group, and in none of the saline controls. The average plasma free hemoglobin values found in the distilled water animals were approximately twice those found in the chlorinated group. This difference was primarily the result of exceptionally high values in only two of the five animals in group II. The individual range of the peak arterial plasma hemoglobin concentration three minutes following aspiration was considerable.

**Serum Electrolytes.** The changes in arterial serum electrolytes are shown in figure 4. Serum sodium and serum chloride showed moderate decreases at one, three, and five minutes postimmersion in the animals that aspired unchlorinated distilled water. The lowest average values were observed at one minute. These changes first appeared and
were most noticeable in arterial blood (sodium 118 mEq./liter; chloride 88 mEq./liter). The lowest average sodium and chloride found in venous blood were 132 mEq./liter and 97 mEq./liter, respectively, in the three-minute samples. Ten minutes post-immersion the arterial and venous electrolyte concentrations were indistinguishable. All values returned to essentially normal levels at the completion of the experiment. The chlorinated group showed a similar pattern but a less severe decline in the one minute arterial samples. The differences observed between the chlorinated and unchlorinated distilled water groups were not significant ($P = > 0.05$). Unlike the animals who aspirated distilled water, the serum sodium and serum chloride remained unchanged in the saline controls ($P = < 0.05$). Serum potassium concentration increased in all of the chlorinated and in four of the animals in the unchlorinated distilled water group; reaching a peak at three minutes and rapidly returning to normal. A transient rise in potassium was also noted in three of five saline control animals. A significant difference between the combined groups 1 and 11 vs. group III was seen only in the one minute samples ($P = < 0.05$). Calcium levels remained essentially normal in all three groups.

Postmortem Findings. The heart was of normal size in all 15 animals. Clear foam was seen in the trachea and major airways of 2 dogs, pink frothy foam in 2 and no evidence of foam or water in the remaining animals, in each of the chlorinated and unchlorinated distilled water groups. Major airways of all animals subjected to normal saline aspiration contained copious amounts of clear white foam and clear free fluid poured out of the airways.

The superior portions of the lungs of all animals were clear and contained air. The four survivors in group I showed scattered areas of hemorrhagic discoloration and atelectasis in the dependant lobes. The dependant portions of the lungs of the dog who succumbed to immersion were heavy, boggy and water logged.
Spotty hemorrhagic and atelectatic areas were also seen in the dependent lobes of 4 animals in group II and in the fifth these areas were boggy and almost confluent hemorrhagic. The dependent lung fields in all of the saline controls were solid, water logged, and consisted of massively confluent, purplish, hemorrhagic areas.

Blood tinged fluid was found in the alimentary tract of some animals after chlorinated and unchlorinated distilled water aspiration.

**Discussion**

In this study, two major deviations from previous experiments were employed: (1) the volume of fluid aspirated was chosen at 10 ml. per pound of body weight, or approximately two times the normal measured tidal volume of the animals; and, (2) all animals were allowed the opportunity to breathe air following immersion. Conceivably these conditions may resemble more closely the situation in the human near-drowning victim who is rescued shortly after onset of immersion than does the technique of prolonged total immersion.

In these studies blood removed for sampling was not replaced by transfusion. It is possible that acute death from primary hypervolemia may have been prevented in the animals by intermittent blood sampling. In subsequent studies performed to determine the effect of aspirating various volumes of chlorinated distilled water, the same experimental protocol was followed but fewer samples were drawn so that blood loss was not major (less than 5 per cent of blood volume). Although there was a slightly greater delay in return to normal of serum electrolytes, the overall trends observed in animals aspirating 10 ml. of water per pound body weight were similar to those reported here.

Although slight differences were noted in the absolute average values for blood constituents, serum electrolytes, and blood volume subsequent to aspiration between the chlorinated and unchlorinated distilled water groups
these differences were not significant. This would tend to negate the hypothesis that chlorine in fresh water significantly alters the rate of passage of fluid from the lungs into the circulatory system.

Although the serum sodium, chloride, and potassium showed transient changes in the arterial blood of the dogs immersed in distilled water with and without chlorine, all these values rapidly returned to normal. If only venous samples were obtained these changes would not have been detected. In addition, all animals showed essentially normal values for hemoglobin, hematocrit, and serum calcium. If one observes all the above values sixty minutes following immersion, the interpretation is one of normal levels. Thus, if a species variation does not exist, we may speculate that the reason the transient changes observed in this study are not seen in human near-drowning victims is that arterial blood is not sampled within the critical first few minutes after onset of immersion. Subsequently, there is a shift of the absorbed fluid and body electrolytes so that blood constituent and serum electrolyte concentrations rapidly return to normal levels despite a persistent elevation in the blood volume. Although these experiments were not designed to study the exact nature of the shifts, there is some indirect evidence that the gastrointestinal tract may receive much of the fluid because blood tinged fluid was found in the alimentary tract of some animals at autopsy.

Ventricular fibrillation has been reported frequently to be the terminating episode in death from experimental fresh water drowning, but its occurrence in man has been confirmed only twice, one a victim of fresh water and the other a victim of sea water aspiration. Ventricular fibrillation did not occur in this study in spite of severe hypoxemia, acidosis, and hyperkalemia (the highest transient serum potassium level observed was 9.7 mEq/liter). Electrocardiographic changes were primarily limited to bradycardia, bigeminy, dropped beats, and elevated T waves, all of which can be attributed to hypoxia and, in some animals, hyperkalemia.

Since the hypotensive episode observed immediately after immersion coincided approximately with the period of apnea (or breath holding), it may have been reflex in origin or secondary to a reduced venous return produced by an increased intrathoracic pressure. On the other hand, the more profound hypotension seen in the fresh water groups suggests it may be secondary to acute cardiac insufficiency resulting from rapid influx of hypotonic solution. If so, larger quantities of aspirated hypotonic water may increase the severity, and further prolong the duration, or both. The hypertensive episode which followed may be attributed to the increased blood volume and the release of catecholamines secondary to acute asphyxia.

Although significant transient changes in blood constituents, electrolytes, and the cardiovascular system were more frequently observed in groups I and II than in the saline controls, the differences were slight after the first ten minutes; subsequently the nature of the aspirated fluid did not appear to be an important factor. It would appear, therefore, that the derangement of the cardiovascular system and blood constituents was not a serious problem in these animals. Kylstra, on the other hand, recently found that the nature of the aspirated fluid does severely alter the cardiovascular changes observed in animals subjected to total immersion.

The arterial blood gas and acid-base studies of all three groups studied were indistinguishable. These data indicate a common respiratory problem regardless of the type of fluid aspirated, i.e., acute asphyxia with persistent severe arterial hypoxemia and metabolic acidosis. The more severe hyperventilation noted in the saline control animals sixty minutes post-immersion was probably related to the slower rate of absorption of fluid from the lungs compared to the chlorinated and unchlorinated distilled water groups. The larger quantity of fluid remaining in the lungs at autopsy and the slower rate of increase in blood volume in this group lend support to this hypothesis.

Interestingly enough, 14 of the 15 animals studied became apneic (or breath-held) within nine seconds of aspiration; however respiratory efforts reappeared spontaneously 14 to 45 seconds following onset of immersion. These data should not be interpreted as implying that drowning or near-drowning victims will resume respiration spontaneously. They do
emphasize, however, that apnea in itself does not necessarily signify permanent cessation of respiration in the drowning victim, nor does the reappearance of spontaneous respiratory movements indicate that recovery is inevitable.

It should be emphasized that the saline group was introduced in this study as an isotonic control (0.9 N) and changes subsequent to its aspiration are not to be confused with those following aspiration of hypertonic seawater (3.5 N).

To further define the relative severity of the respiratory and cardiovascular abnormalities when different quantities of fresh water are aspirated, studies with graduated volumes of water are now in progress. It is anticipated that the relative severity of the cardiovascular and blood constituent problems will increase proportionately with an increase in volume. At lesser volumes the problem requiring therapy will be primarily respiratory.  

Summary and Conclusions

The changes in serum electrolytes and blood constituents reported subsequent to fresh water aspiration in human near-drowning victims have appeared to conflict with studies on drowning in the dog. Mongrel dogs were exposed to aspiration of 10 ml. per pound of chlorinated distilled water, unchlorinated distilled water, or physiological saline solution. In all three types of aspiration an identical picture was observed of acute asphyxia with hypoxemia, hypercapnia and acidosis. Although significant deviation from normal was observed acutely following fresh water aspiration, ten to sixty minutes postimmersion all three groups were indistinguishable and demonstrated essentially normal blood constituents and electrolyte values, except for persistent arterial hypoxemia and metabolic acidosis.

Thus the dog shows physiological changes similar to those of man following near-drowning in fresh water. There is a rapid redistribution of absorbed fluid and, provided that the animal survives the initial asphyxia, serum electrolytes and blood constituents rapidly return to normal. The presence of chlorine in distilled water does not significantly alter the respiratory, biochemical, or cardiovascular response to aspiration. Physiological saline solution in the pulmonary tree is not innocuous, and aspiration or instillation of large volumes into the trachea may have serious respiratory consequences.

References