Serum Electrolyte Concentrations after Fresh-water Aspiration:

A Comparison of Species

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Rabbits were subjected to aspiration of 10 ml or 20 ml of distilled water per pound body weight: all became hypoxic. Changes in electrolytes, hemoglobin, hematocrit, and plasma hemoglobin were not severe after aspiration of 10 ml of water per pound. However, animals that aspirated 20 ml per pound showed severe hemodilution, hemolysis and electrolyte changes. We conclude that, although concentrations of sodium and potassium in the erythrocytes of rabbit and dog differ, changes in serum sodium concentrations are similar in both species after aspiration of 10 ml of fresh water per pound body weight. When 20 ml/lb is aspirated, potassium changes are similar in both species, but the degree of hyponatremia is greater in the rabbit. The possible application of the data to humans is discussed. Evidence that ventricular fibrillation after fresh water aspiration is not dependent on hypoxia and hyponatremia alone is also presented.

IT HAS BEEN SUGGESTED that fresh-water drowning victims die of ventricular fibrillation from the combined effects of hypoxia and hyponatremia.[1] Study of human fresh-water drowning victims showed that the serum chloride concentration in blood taken from the left ventricle was within 20 mEq/l of normal in 86 per cent, and the serum sodium within 20 mEq/l of normal in 84 per cent.[2] When these values are correlated with experimental results in dogs,[2,3,4] they suggest that these subjects aspirated 10 ml or less of fluid per pound body weight. Therefore, ventricular fibrillation is unlikely to have caused death.[2,3,4] However, concentrations of sodium and potassium in erythrocytes of man and dog are not comparable.[5] Since hemolysis occurs after aspiration of fresh water, it is important to compare electrolyte changes in dogs with those in animals with electrolyte concentrations similar to man in both erythrocytes and plasma. The rabbit, therefore, was selected for this study.[5]

Methods

Ten New Zealand white rabbits (weights 8 to 11 lb) were randomly divided into two groups and anesthetized by slow intravenous titration with sodium pentobarbital (Nembutal) (total dose, 9–11 mg/lb). Each animal was then placed supine and a polyethylene catheter threaded via the left femoral artery into the abdominal aorta. The trachea was exposed in the neck and intubated with a snug-fitting polyvinyl endotracheal tube (18–20 French). Lead II of the electrocardiogram was recorded continuously.

A heparinized arterial blood sample (0.5 ml) was drawn anaerobically and analyzed within two minutes for *p*H, P_{O_2} and P_{CO_2} by direct-reading electrodes in an IL 113-S1 apparatus at 37 C. One ml of blood was drawn into a second heparinized syringe for whole-blood studies and 2 ml into a dry syringe for serum analysis. Care was taken to minimize hemolysis and stasis of blood in the catheters by removing 3 ml immediately before samples were withdrawn. This blood was then reinfused into the animal following sampling. Total hemoglobin was determined by the

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TABLE 1. Heart Rate (Beats/Min) after Aspiration of Distilled Water*

Minutes Post-aspiration	Group I		Group II	
	Mean	SD	Mean	SD
0	282	17	261	38
1	255	30	171	76
2	272	21	120	31
3	252	34	94†	39
5	255	18	55‡	9
10	267	22	—§	—

* The five rabbits in Group I aspirated 10 ml distilled water per pound body weight. The five rabbits in Group II aspirated 20 ml/lb.
† Four animals (one dead).
‡ Three animals (two dead).
§ All animals dead.

cyanmethemoglobin method and hematocrit by a Guest-Weichselbaum microcapillary centrifuge. An aliquot of blood was centrifuged, plasma removed and hemoglobin content analyzed by a modified version of the Bing and Baker technique.[6] Serum studies included determination of sodium and potassium concentrations with an Instrumentation Laboratories flame photometer. Serum chloride was determined with a Buchler-Cotlove chloridometer. The above-mentioned samples were drawn five minutes prior to aspiration of fluid, and will be referred to as "control" or "zero time" samples.

The endotracheal tube was connected via a "Y" adapter to a water reservoir and breathing bypass similar to that described previously.[4] Ten seconds later, at "zero time," the bypass was occluded and one group of rabbits aspirated 10 ml of distilled water per pound of body weight. When water had cleared from the tubing, the animals were disconnected from the reservoir to minimize ventilatory deadspace. Three, ten and 60 minutes after onset of aspiration, arterial blood was sampled and laboratory determinations repeated. Sixty-five minutes after aspiration all surviving animals were sacrificed by exsanguination for gross examination of the lungs.

The second group of animals was treated identically but subjected to aspiration of 20 ml of distilled water per pound body weight, a volume representing total immersion, as none of the animals cleared the chamber of water completely. Since all animals in this group died within ten minutes of aspiration, serum electrolyte values at ten minutes were determined in blood drawn postmortem by cardiac puncture.

Results

SURVIVAL DATA AND EKG CHANGES

All rabbits that aspirated 10 ml of water per pound survived the one-hour experiment. Thirty-five to 50 seconds (mean, 44 seconds) were required to empty the drowning chamber. The only consistent electrocardiographic change after aspiration was a slight decrease in heart rate (table 1). Three of the five rabbits had transient changes in rhythm or in the character of the QRS complex, and one had a temporary increase in the amplitude of the T wave.

TABLE 2. Means and Standard Deviations for Arterial Blood Gas, Hemoglobin, Hematocrit and Plasma Hemoglobin Values after Aspiration of Distilled Water

	Minutes Post-aspiration	pH	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)	Hemoglobin (gm per cent)	Hematocrit (volumes per cent)	Plasma Hemoglobin (mg/100 ml)
Group I (10 ml/lb)	0	7.48 ± 0.05	69 ± 7	32 ± 3	11.7 ± 1.2	33 ± 3	39 ± 24*
	3	7.45 ± 0.04	43 ± 14†	31 ± 2	11.5 ± 1.5	34 ± 4	140 ± 34†
	10	7.51 ± 0.06†	50 ± 16†	32 ± 7	11.5 ± 1.1	33 ± 3	133 ± 46†
	60	7.59 ± 0.06†	40 ± 25†	25 ± 6†	11.4 ± 1.2	33 ± 2	100 ± 34†
Group II (20 ml/lb)	0	7.44 ± 0.14	70 ± 6	31 ± 4	11.6 ± 1.0	33 ± 2	45 ± 28*
	3	7.31 ± 0.09†	13 ± 6†	33 ± 4	7.3 ± 0.7†	20 ± 3	4104 ± 2515†

* The high control values for plasma hemoglobin are attributed to difficulty in separation of plasma and cells with the small samples of heparinized blood used in this study.
† Mean change from control value significant ($P < .05$).

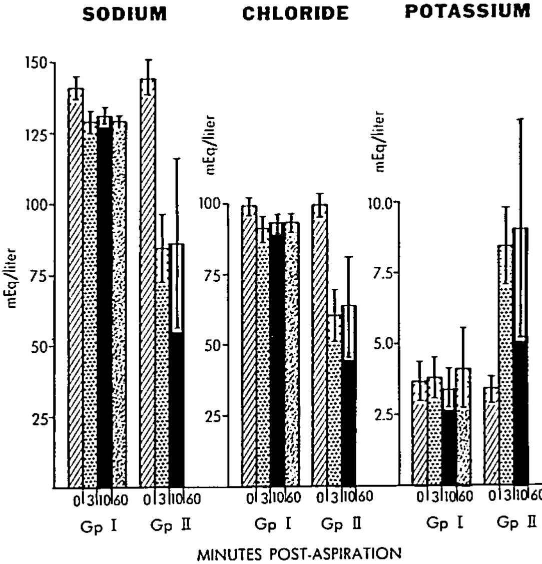

FIG. 1. Means and standard deviations of serum sodium, chloride and potassium concentrations prior to and following aspiration of distilled water. The rabbits in group I aspirated 10 ml of distilled water per pound body weight and those in group II aspirated 20 ml per pound.

None of the animals subjected to aspiration of 20 ml/lb of fresh water emptied the water chamber completely; all died within ten minutes of aspiration. One animal developed bradycardia, then died with ventricular fibrillation two minutes 38 seconds after aspiration. The other four animals showed progressive bradycardia with irregular beats, intermittent disappearance of the P wave, and broadening and flattening of the QRS complex. Three rabbits also had increases in the amplitude of the T wave within two minutes of aspiration.

Arterial Blood Gas Changes (Table 2)

The Pa_{O_2} fell three minutes postaspiration in all rabbits ($P < 0.01$); the magnitude being greater in those that aspirated 20 ml than in those that aspirated 10 ml per pound ($P < 0.01$). Arterial hypoxemia was still seen in four of the five survivors 60 minutes postaspiration. The *p*H also decreased three minutes postaspiration in every animal, being significantly lower after aspiration of 20 ml than after 10 ml per pound ($P < 0.01$). By 60 minutes postaspiration every survivor had an increase in *p*H and corresponding decrease in Pa_{CO_2}.

Hemoglobin, Hematocrit and Plasma Hemoglobin (Table 2)

The plasma hemoglobin concentration increased in all animals studied ($P < 0.05$); it was greater after aspiration of 20 ml per pound ($P < 0.05$). Hemolysis was not reflected in the whole-blood hemoglobin and hematocrit levels of animals that aspirated 10 ml per pound. Significant decreases in both whole-blood hemoglobin and hematocrit were seen, however, three minutes following aspiration of 20 ml per pound ($P < 0.001$). The plasma hemoglobin levels decreased progressively with time in the survivors; however, significant elevation was still seen 60 minutes postaspiration ($P < 0.01$).

Serum Electrolytes (Figure 1)

Serum sodium and chloride concentrations decreased in all animals after aspiration of water ($P < 0.05$). The magnitude of change was less after aspiration of 10 ml than after 20 ml per pound ($P < 0.05$). The greatest change after aspirating 10 ml per pound was a fall in sodium of 18 mEq/l three minutes postaspiration. After aspiration of 20 ml per pound, serum chloride fell at least 31 mEq/l, and serum sodium at least 44 mEq/l, in all animals. There was no significant change in serum potassium concentration after aspiration of 10 ml per pound ($P > 0.2$). Two animals showed slight increases in potassium, and three, decreases, range −0.6 to +1.2 mEq/l. Conversely, serum potassium concentrations increased in all animals within three minutes of aspirating 20 ml per pound; the range of values was +3.5 to +6.4 mEq/l ($P < 0.001$).

Necropsy Findings

The lungs of all animals studied one hour after aspiration of 10 ml per pound were similar, showing scattered petechial areas of collapse and reddish discoloration throughout. However, most areas contained air. The lungs of the rabbits that died after aspiration of 20 ml per pound were distended, heavy and boggy. The lungs were pale, taking on the clear color of the water with no evidence of air or crepitus.

Discussion

We have previously found the occurrence of ventricular fibrillation during fresh-water drowning to be volume-dependent,[3] occurring in approximately 80 per cent of dogs after aspiration of at least 20 ml of fresh water per pound body weight, but not when 10 ml or less was aspirated.[3,4] The change in serum sodium concentration was also volume-dependent, decreasing less than 20 mEq/l when 10 ml per pound of distilled water was aspirated, but averaging 35 mEq/l below normal after aspiration of 20 ml per pound.[3] In a study of 74 human fresh-water drowning victims, serum sodium concentration of blood taken from the left ventricle was within 20 mEq/l of normal in 84 per cent of the victims.[2] If man and dog can be compared, this suggests these patients aspirated 10 ml of water per pound body weight or less.

Although sodium and potassium concentrations in serum are similar in man and dog, the concentrations in erythrocytes are reversed (man: K = 136 mEq/l, Na = 19 mEq/l; dog: K = 10 mEq/l, Na = 135 mEq/l).[5] Since hemolysis occurs after fresh-water aspiration, releasing both ions into the plasma, direct comparison between data collected in these two species can be questioned. The rabbit, on the other hand, has erythrocytes with concentrations of potassium and sodium similar to those in humans (K = 142 mEq/l, Na = 22 mEq/l).[5] Rabbits that aspirated 10 ml of fresh water per pound body weight in the present study showed changes in serum sodium concentration of less than 20 mEq/l, while sodium decreased at least 40 mEq/l after aspiration of 20 ml per pound. The potassium concentration was also related to quantity of water aspirated, remaining unchanged after aspiration of 10 ml, but increasing after aspiration of 20 ml per pound.

When these changes in sodium were compared with those in previous studies in dogs,[3,4] there was no significant difference between the two species after aspiration of 10 ml of distilled water per pound ($P > 0.05$). When 20 ml per pound was aspirated, the magnitude of hyponatremia was greater in the rabbit (ΔNa -60 ± 12.7* mEq/l) than in the dog (ΔNa -31 ± 8.5 mEq/l) ($P < 0.01$). No significant differences were seen between changes in serum potassium (rabbit $\Delta K = 5.0 \pm 1.3$ mEq/l; dog $\Delta K = 4.1 \pm 2.4$ mEq/l; $P > 0.05$) and chloride (rabbit ΔCl -39 ± 7.6 mEq/l; dog ΔCl -29 ± 8.0 mEq/l; $P > 0.05$), however. The difference between sodium levels in the rabbit and dog after aspirating 20 ml/lb can be attributed to the release of sodium from hemolyzed erythrocytes in the dog. One might expect the potassium level to be higher in the rabbit for similar reasons; however, comparable increases were seen in both species. This could be due to the release of potassium secondary to acute severe hypoxia in the dog, as similar changes occurred in this species when 10 ml per pound was aspirated.[3] These data suggest it is reasonable to compare serum

* Mean ± standard deviation.

electrolyte changes in rabbits, dogs and man following aspiration of 10 ml of fresh water per pound of body weight. When levels of serum sodium in the dog after aspiration of 20 ml per pound are used for comparison with rabbits (and presumably, humans), the volume of water aspirated in the latter two species will be overestimated. This, then, strengthens the conclusions in the companion paper[2] regarding quantities of water aspirated by human fresh-water drowning victims.

The results reported in the companion paper[2] suggest that 84 per cent of human fresh-water drowning victims aspirate 10 ml of water per pound or less and, therefore, die of causes other than hyponatremia and ventricular fibrillation. Changes in arterial oxygen tension in this study, as well as those reported in other animal experiments[3,4,7] and following human near-drowning,[8] point toward profound hypoxia as the most important precipitating factor in the death of these patients.

One rabbit died of ventricular fibrillation after aspirating 20 ml of fresh water per pound body weight, yet the serum sodium concentration, 88 mEq/l, was higher than those in three other rabbits in the same group that did not fibrillate. This suggests that hyponatremia and hypoxia alone do not always produce ventricular fibrillation after fresh-water drowning. Gordon, Raymon and Ivy suggested this might be a species-variable phenomenon.[9] Although the incidence of ventricular fibrillation after fresh-water drowning is greater in dogs than in rabbits[3,9] it occurs in both species. Further study appears necessary before the exact mechanism precipitating ventricular fibrillation after fresh-water aspiration is definitely established.

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