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Vitreous Humor Chemistry in Deaths Associated with Rapid Chilling and Prolonged Freshwater Immersion

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ABSTRACT: Vitreous humor chemistry studies were performed on 13 air crash victims who had remained immersed in near-freezing fresh water for seven to eight days. Glucose concentrations were observed to be higher than those in a comparison group of autopsied cases with prolonged postmortem intervals, suggesting that rapid chilling inhibited glycolysis. Evidence of dilution of vitreous humor electrolytes was also noted. After correction for the apparent degree of dilution, the potassium concentrations were found to fall within a narrow range.

KEYWORDS: pathology and biology, vitreous humor, death, chilling, glycolysis, postmortem interval

Following the crash of Air Florida Flight 90 into the Potomac River on 13 Jan. 1982, 74 victims were recovered sequentially from the submerged wreckage over an eleven-day period. Vitreous humor chemistry studies were performed on a group of cases toward the end of the recovery operation to determine whether the chemistry values might reveal a distinctive pattern related to the circumstances of death, the postmortem interval, or to prolonged immersion in near-freezing fresh water.

Materials and Methods

Vitreous humor was obtained from 13 adult victims at the time of autopsy, on the seventh and eighth days after the crash. In none of these cases was there evidence of significant preexisting illness on the basis of gross examination. Little warming of the bodies had taken place by the time of autopsy. Core temperatures as low as 4°C (37°F) were recorded in some cases. All the bodies were well preserved, and the vitreous fluid was clear. A standard SMA-6 analysis was performed by autoanalyzer. Glucose determination was by a hexokinase method.

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Results

The results of the study are presented in Table 1. To determine whether these values differed from those we were accustomed to seeing in other cases, we selected a comparison group from other autopsied cases in which there was evidence of a prolonged postmortem interval, based on a vitreous humor potassium concentration greater than 10.0 meq/L. We collected all such cases over an approximately two-month interval centered about the time of the plane crash, for a total of 13 cases. These individuals died from a variety of natural causes. None of the deaths was related to cold exposure. The chemistry values for the comparison group are shown in Table 2.

We were able to make several observations based on these two sets of results. The first was that the vitreous humor glucose concentration was significantly higher in the crash victims than in the comparison group ($P < 0.0005$ by paired t test). There was virtually no overlap between the two groups (Fig. 1).

We also noted that, although there was wide variation in the vitreous humor potassium concentration among crash victims with the same postmortem interval, there appeared to be a regular relationship between the concentrations of potassium, sodium, and chloride in these cases. Figure 2 shows the relationship between potassium and chloride concentrations for the nine individuals with a postmortem interval of eight days. There is a positive correlation between the potassium and chloride concentrations ($P < 0.001$). There is a similar positive correlation between potassium and sodium. There was no predictable relationship between potassium and sodium or potassium and chloride in the comparison group (data not shown).

TABLE 1—*Vitreous humor chemistry values in 13 air crash victims.*

Case	Postmortem Interval, days	Glucose, mg/dL	VUN, mg/dL	Sodium, meq/L	Potassium, meq/L	Chloride, meq/L	Carbon Dioxide, meq/L
1	7	68	12	95	20.0	75	8
2	7	98	11	100	23.0	85	7
3	7	65	14	105	25.6	80	4
4	7	82	9	100	27.0	95	5
5	8	60	12	104	25.0	78	6
6	8	75	15	102	24.4	73	7
7	8	85	19	105	25.6	77	10
8	8	80	10	95	19.1	68	7
9	8	74	11	75	18.7	55	5
10	8	75	14	103	25.3	80	7
11	8	55	10	80	18.4	60	5
12	8	70	20	85	21.9	68	4
13	8	65	20	90	23.1	70	7
Mean values	...	73.2	13.6	95.3	22.8	74.1	5.6

TABLE 2—*Vitreous humor chemistry values associated with potassium greater than 10.0 meq/L (death from natural causes).*

	Glucose, mg/dL	VUN,[a] mg/dL	Sodium, meq/L	Potassium, meq/L	Chloride, meq/L	Carbon Dioxide, meq/L
Mean	34.8	12.3	136	15.8	114	10
Range	12-65	3-23	104-148	10.6-30	102-125	2-16

[a]Two urea nitrogen values of 78 and 212 mg/dL were excluded in calculating mean and range for VUN.

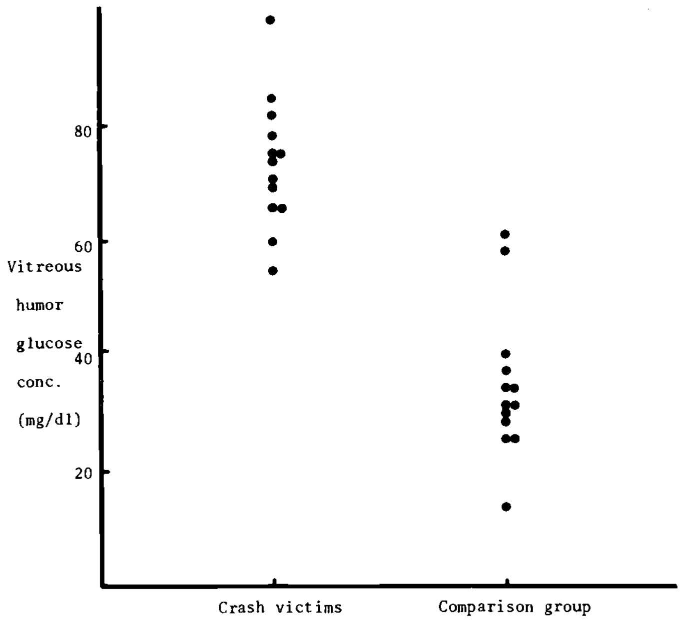

FIG. 1—*Vitreous humor glucose concentrations in the two groups.*

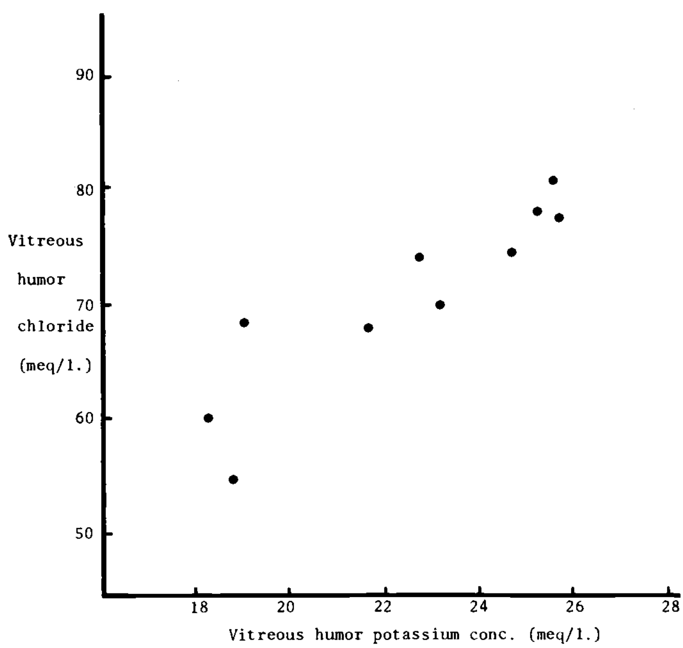

FIG. 2—*Vitreous humor potassium and chloride concentrations in crash victims with postmortem interval of eight days.*

The discovery of a relationship between potassium, sodium, and chloride concentrations prompted us to look for a relationship between potassium and urea nitrogen levels and potassium and glucose. Examination of Table 1 shows a tendency for the higher potassium concentrations to be associated with higher urea nitrogen values, but the tendency is not statistically significant. As shown in Fig. 3, glucose values appear to be randomly distributed with respect to potassium concentration. The values of total carbon dioxide also appear to be unrelated to concentrations of the other solutes.

Discussion

Most of the published work in the area of postmortem vitreous humor chemistry has been reviewed by Coe [*1*]. He cites his own studies and those of others in reaching the following conclusions regarding postmortem changes in the concentrations of the solutes studied in our investigation:

1. The glucose concentration falls as a result of anaerobic glycolysis, frequently to near-zero levels within hours after death. The normal vitreous concentration in life appears to be about 85% of the blood glucose level [*2,3*].

2. The vitreous urea nitrogen (VUN) concentration approximates the blood level and either remains stable or rises very slightly postmortem [*2,4*].

3. A prolonged postmortem interval gives rise to a "decomposition pattern," in which the potassium concentration is markedly elevated and the sodium and chloride concentrations are decreased. This pattern is caused by the diffusion of ions between the intracellular and extracellular spaces [*1,5-7*].

We found that the glucose concentration in the vitreous humor of the plane crash victims was significantly higher than values obtained in a comparison group. This effect on glucose concentration appears to be the result of rapid chilling of the eye at the time of death caused

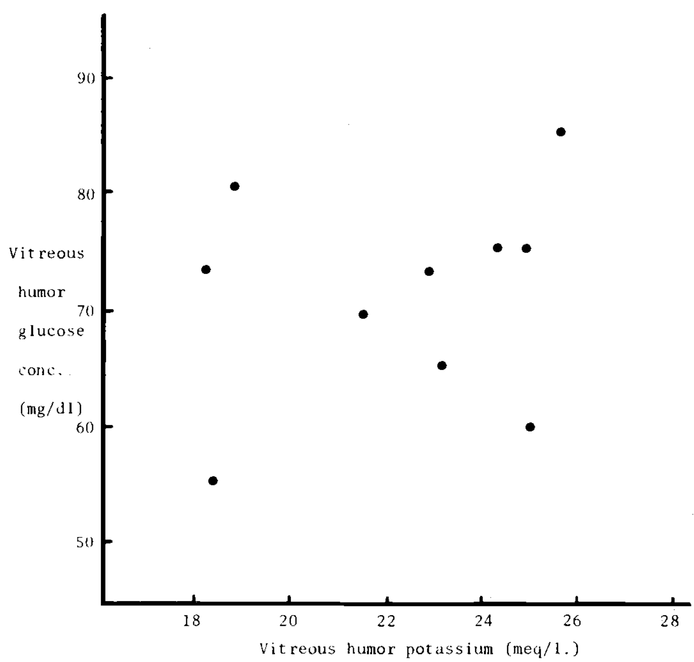

FIG. 3—*Vitreous humor potassium and glucose concentrations in crash victims with postmortem interval of eight days.*

by cold water immersion, halting glycolysis by inactivating glycolytic enzymes. We do not know whether glycolysis would have resumed had the bodies rewarmed to room temperature, nor do we know how rapidly chilling must take place for this effect on glucose concentration to be seen. Further study, especially of deaths caused by cold exposure, is indicated.

The finding of a direct relationship between potassium concentration and the sodium and chloride concentrations was unexpected. The concept of a "decomposition pattern" had led us to anticipate that the highest potassium concentrations would tend to be found in those cases with the lowest sodium and chloride values, while the opposite proved to be true. Our results indicated that in the crash victims some process took place that caused the concentrations of potassium, sodium, and chloride to be altered in the same direction. The simplest explanation for these findings is that there was dilution of the contents of the eye by fresh water. The degree of dilution apparently varied from one individual to the next. The cause of individual variation in the degree of dilution is not clear.

As mentioned above, there was no predictable relationship between potassium concentration and the glucose level, and only a weak positive correlation with urea nitrogen values. This does not argue against a dilution effect, since the variation in glucose and urea nitrogen concentrations from one case to the next may be largely the result of individual differences in the vitreous humor concentrations of these substances at the time of death. One would expect greater individual variation in glucose and urea nitrogen than in the levels of potassium, sodium, and chloride, which in life are so tightly regulated. Individual differences in the vitreous humor concentrations of glucose and urea nitrogen premortem may obscure the effect of dilution on their postmortem levels.

Individual variation in the degree of fresh-water dilution helps to account for some of the variability in potassium concentration in cases with the same postmortem interval. This can be demonstrated by examining values from our nine cases with a postmortem interval of eight days. If one assumes that the case with the highest chloride concentration shows the least degree of dilution, then the potassium concentrations can be "corrected" using the formula:

$$(\text{corrected potassium})_n = (\text{measured potassium})_n \times \frac{(\text{highest chloride})}{(\text{chloride}_n)}$$

The "corrected" potassium values are shown in Table 3. By adjusting for the apparent degree of dilution of electrolytes, the range of potassium concentrations is reduced by 35%. No "corrected" value differs by more than 12% from the mean of 25.6 meq/L. This supports Coe's conclusion that the vitreous humor potassium concentration shows the least individual variation of those chemical determinations used to estimate the postmortem interval [*1*]. However, the limitations of the vitreous humor potassium in this regard may be shown by comparing the group of cases with a known postmortem interval of seven days with the group with an interval of eight days. The mean potassium concentration, both "corrected" and uncorrected, is higher at seven than at eight days.

Most studies in the literature on the chemical changes associated with aqueous immersion have focused on serum electrolyte changes in drowning and near-drowning; only two have examined vitreous humor chemistry. Adjutantis and Coutselinis [*8*] studied the effects of seawater submersion on exenterated human eyeballs, and demonstrated the movement of magnesium ions into the vitreous humor. Sturner et al [*9*] used bovine eyeballs in a similar, but more extensive study. They found that the vitreous potassium concentration plateaued at 12 to 13 meq/L after 16 h in seawater (potassium concentration 0.15 meq/L). If such plateauing occurred in our cases, it obviously took place at much higher potassium levels. This may mean that the soft tissues and blood surrounding the eye can serve as a reservoir of potassium ions. The lower values measured by these authors may have been a result of their use of exenterated eyeballs, which lack such an ion reservoir. A plateau effect could help explain why the potassium concentrations in our cases are so similar at postmortem intervals of seven and eight days. It is possible that peak potassium values were reached before seven days, and that a variable degree of dilution subsequently occurred.

TABLE 3—*"Correction" of vitreous humor potassium concentration for apparent degree of freshwater dilution; postmortem interval of eight days.*

Case	Chloride, meq/L	Potassium, meq/L	"Corrected Potassium," meq/L
5	78	25.0	25.6
6	73	24.4	26.7
7	77	25.6	26.6
8	68	19.1	22.5
9	55	18.7	27.2
10	80	25.3	25.3
11	60	18.4	24.5
12	68	21.9	25.7
13	70	23.1	26.4

Sturner et al also reported the movement of water out of the eye into surrounding hyperosmolar seawater, and of magnesium and chloride ions from seawater into the vitreous humor. Based on their findings and ours, it appears that dilution of vitreous electrolytes in freshwater submersion may be caused both by entering the hypersomolar vitreous humor and ions diffusing out of it.

We did not expect that vitreous humor chemistry studies would help to clarify the extent to which drowning was a contributory factor in causing death in addition to the trauma suffered by the crash victims. No correlation was observed between the degree of pulmonary congestion and edema, common anatomic correlates of drowning, and the concentrations of any of the solutes measured in our investigation.

This study appears to demonstrate that rapid chilling inhibits the postmortem fall in vitreous humor glucose concentration. It also demonstrates dilution of vitreous humor electrolytes in the course of freshwater immersion. Individual variation in the degree of dilution should be kept in mind in attempting to interpret vitreous humor chemistry results in cases of prolonged submersion.

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