John I. Coe,[1] *M.D.*

Hypothermia: Autopsy Findings and Vitreous Glucose

REFERENCE: Coe, J. I., **"Hypothermia: Autopsy Findings and Vitreous Glucose,"** *Journal of Forensic Sciences*, JFSCA, Vol. 29, No. 2, April 1984, pp. 389-395.

ABSTRACT: Anatomic lesions associated with hypothermia are variable and nonspecific. Only a few gross lesions and no microscopic pathology were noted in the acute deaths of this series. An interesting anatomic observation was the low weight of the lungs in 45% of the hypothermic deaths. Hypothermia is recognized as frequently producing hyperglycemia and 80% of a group of such patients clinically treated at the Hennepin County Medical Center had elevated blood sugar values. This correlates with an average vitreous glucose of 82.6 mg/dL in the hypothermic deaths. By contrast, the average vitreous glucose value found in each of two separate control groups was 37 mg/dL.

Establishing hypothermia as the cause of death requires a proper history of exposure and the absence of any other clear-cut lethal factor. Certain biochemical tests may provide supporting evidence. Among these is an elevated vitreous glucose in a nondiabetic individual.

KEYWORDS: pathology and biology, hypothermia, vitreous humor

Death from hypothermia is difficult to verify, because there are no diagnostic autopsy findings. Gross lesions that have been observed include swollen, discolored extremities, ears, and nose; hemorrhage or petechial ulcers of the gastric mucosa; and hemorrhagic pancreatitis [*1-3*]. Microscopic foci of myocardial degeneration have been described [*2,3*]. The skin changes are suggestive but not diagnostic of frostbite, and all the internal findings, both gross and microscopic, are manifestations of stress that may be found in other conditions than hypothermia. As a consequence, the diagnosis of death from hypothermia is made by a combination of observations, including an appropriate history of exposure, certain nonspecific pathological finds when present, and the absence of other lethal factors.

Recently, Hirvonen and Huttunen [*3*] have advocated the study of urinary catecholamines as a possible aid in diagnosing deaths from hypothermia. A still more recent study by Bray et al [*4*] concerning vitreous humor chemistry in deaths associated with rapid chilling and prolonged fresh water immersion demonstrated a significantly higher vitreous glucose level than found in the control group. Dr. Bray in a personal communication stated that he was also finding elevated vitreous glucose values in all victims dying in a cold environment.[2] These observations have stimulated interest in reviewing the effects of hypothermia on vitreous chemistries seen in Hennepin County, Minnesota. It was also decided to catalog the autopsy findings in the hypothermia deaths, for comparison with published series.

[1]Chief of pathology, Hennepin County Medical Center and medical examiner, Hennepin County, Minneapolis, MN.

[2]M. Bray, personal communication, Washington, DC, 1983.

Materials and Methods

Chemical Studies

The records of the Hennepin County Medical Examiner's Office contain 38 deaths classified as resulting from hypothermia from 1970 through 1982, a period during which postmortem vitreous studies had become fairly routine. Twelve of these cases were unsuitable for biochemical evaluation. One of the individuals was a known diabetic. In three cases, no vitreous chemical analyses had been performed; in the remaining eight cases the individuals were found alive, but expired after varying periods of hospitalization from some complication of their hypothermia. The records of the remaining 26 cases indicated that 8 of the adults were exposed because of organic brain disease, that is, they were confused individuals who wandered out in the cold and were found dead hours to several days later. These deaths were all classified as accidents, although the possibility of suicide could not always be excluded. In 14 cases, acute alcoholism was considered the precipitating factor in the exposure; the postmortem blood alcohol values ranged from 0.16 to 0.35% in this group. Two elderly adults developed hypothermia because the heat in their homes had been turned off by public utilities. One man was accidentally locked in a box car for several days in midwinter, and an infant was deliberately placed out-of-doors in subzero weather by the unwed mother. Vitreous humor in these cases was obtained in a manner previously described [5] and chemically analyzed by using a Technicon SMA-6. This gave values for sodium, potassium, chloride, urea nitrogen, and glucose using standard methods for electrolytes and urea nitrogen. Glucose was determined by a glucose oxidase technique.

To establish a base against which to compare chemistries from the hypothermic deaths, two control groups were developed from material in the Hennepin County Medical Examiner's Office. The first, designated Group B, comprised 100 consecutive postmortem vitreous glucose values obtained from nondiabetic individuals. The ages ranged from infancy to adults in their 80s; all of these subjects died indoors or in situations in which the environmental temperatures would not have produced or contributed to hypothermia. They died from a wide variety of causes, including natural disease, trauma, and drug overdose. A second group, designated Group C, consisted of 27 acute traumatic deaths in adults occuring out-of-doors during the winter months (1 November to 28 February) over the last 10 years. The majority of these were homicides dying from gunshot wounds (eight cases), manual strangulation (seven cases), or blunt force injuries (three cases). Other deaths were suicides by hanging or gunshot wound occurring out-of-doors. All bodies in this group were very hypothermic and several were completely frozen when found.

Finally, emergency room records of 40 nondiabetic individuals admitted to the Hennepin County Medical Center for hypothermia were reviewed. Ages varied from 18 to 83 years. The cases included 27 males and 11 females. The initial rectal temperatures obtained varied from 23 to 35°C (74 to 95°F), with an average of 30.9°C (87.6°F).

Autopsy Studies

Complete autopsy protocols were available for 22 of the adults and the 1-day-old infant. Routine sections of major body organs stained with hematoxylin and eosin were available for review. No special stains had been prepared in any case.

Results

Chemical Studies

The age, sex, and vitreous chemical values for the deaths from hypothermia are given in Table 1. The values for electrolytes are within the expected range, except for the evidence of

TABLE 1—*Deaths from hypothermia.*

Case	Sex	Age, Years	Vitreous Values				
			Sodium, meq/L	Potassium, meq/L	Chlorine, meq/L	Urea Nitrogen, mg/dL	Glucose, mg/dL
1	F	75	139	6.5	120	28	104
2	M	47	133	18.5	...	15	68
3	M	63	125	19.7	114	10	93
4[a]	M	74	140	5.4	124	8	78
5[a]	F	46	133	6.9	115	12	113
6	M	97	177	9.4	136	43	158
7	F	81	139	8.4	119	38	18
8	F	70	144	7.9	122	13	99
9	M	76	132	17.1	118	20	71
10[a]	F	12	143	6.4	133	10	69
11[a]	M	23	138	6.7	125	14	40
12	F	83	138	6.7	123	14	97
13[a]	F	52	137	9.7	128	8	137
14[a]	M	36	135	5.5	119	11	88
15[a]	M	64	139	7.7	...	16	30
16[a]	F	35	146	8.2	...	10	65
17	M	59	...	...	...	67	100
18[a]	M	55	149	6.2	128	14	120
19[a]	M	70	122	22.0	107	17	170
20	F	65	153	7.8	122	28	90
21[a]	M	61	138	15.0	108	30	25
22[a]	M	34	134	15.1	117	15	20
23[a]	M	46	146	6.0	129	7	56
24[a]	M	20	149	7.8	130	14	23
25	F	88	151	4.9	125	34	119
26	F	1 day	104	30.1	...	...	96

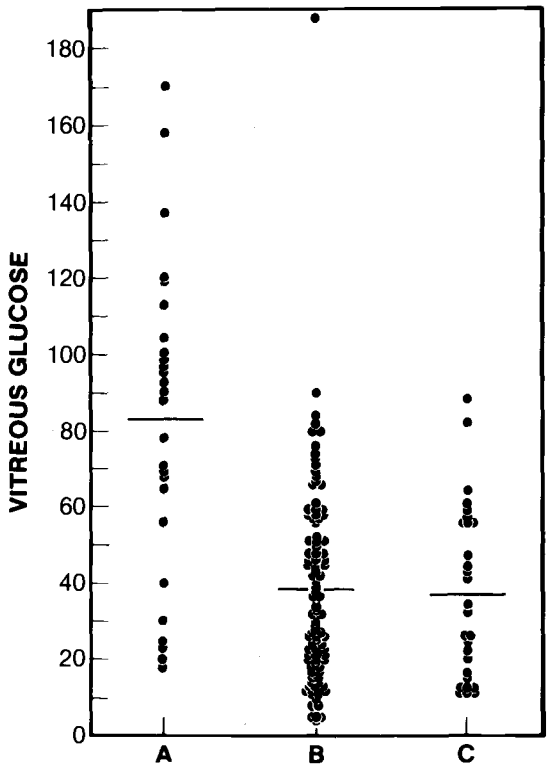
[a] Intoxicated individuals (blood alcohol 0.16 to 0.35%).

dehydration apparent in Case 6 [6, 7]. The low sodium values noted in Case 3, 19, and 26 simply reflect a "decomposition pattern," the result of long postmortem intervals, as attested by the accompanying high potassium values [6, 7]. The vitreous potassium values for the entire group ranged from 4.9 to 30 meq/L, with an average of 10.6 meq/L. Glucose values ranged from 18 to 170 mg/dL, with a mean of 82.6 mg/dL and a standard deviation of 40.5 mg/dL. The mean has a 95% confidence interval of being between 66.5 and 98.7 mg/dL. The distribution of the glucose values in these 26 cases is shown diagramatically in Column A of Fig. 1.

The vitreous glucose values for Group B, the 100 successive routine medical examiner's cases dying at room temperature, ranged from 5 to 188 mg/dL. They are plotted in Column B of Fig. 1. Disregarding the single aberrant high value, the mean glucose level was 37 mg/dL, with a standard deviation of 22.7 mg/dL. A 95% confidence interval for the mean was between 27.2 and 45.8 mg/dL. The vitreous potassium values for this group ranged from 4.8 to 23 meq/L with a mean of 7.9 meq/L.

The vitreous glucose values for Group C, the 27 acute traumatic deaths occurring out-of-doors during winter months, ranged from 11 to 88 mg/dL with a mean of 37 mg/dL and a standard deviation of 22.0 mg/dL. They are plotted in Column C in Fig. 1. A 95% confidence interval for the mean was between 32.6 and 41.4 mg/dL. The vitreous potassium values in this group ranged from 5.3 to 29 meq/L, with a mean of 9.6 meq/L.

The admission emergency room blood glucose values obtained from the 40 nondiabetic individuals admitted to the hospital with hypothermia ranged from 18 to 564 mg/dL, with a



A- Hypothermia Deaths. Mean vitreous potassium for group equals 10.6 mEq/L.

B- 100 consecutive routine medical examiners cases. Mean vitreous potassium for group equals 7.9 mEq/L.

C- Acute tramatic deaths occurring outdoors in winter Mean vitreous potassium for group equals 9.6 mEq/L.

FIG. 1—*Distribution of glucose values.*

mean of 165 mg/dL. Five of these cases had blood glucose levels exceeding 300 mg/dL and thirty-two exceeded 90 mg/dL, which is the upper limit of normal for fasting blood sugar in our laboratory. The degree of hypothermia and the blood glucose values were not proportional. Two of the cases with blood glucose values over 300 mg/dL had only small depressions of core temperature; whereas, one individual with a blood glucose of 37 mg/dL was the most profoundly chilled of any of the subjects in the series.

Autopsy Studies

In the 22 adult hypothermia deaths in which autopsies had been performed, only 3 cases demonstrated potentially lethal lesions. These three individuals had marked coronary atherosclerosis. The remaining 19 cases were coded as having no anatomic cause of death.

In examining for the gross lesions previously described in the literature for deaths from hypothermia, little correlation with the published series could be found. No evidence of frostbite was apparent in any of these victims. The extremities and face tended to display varying degrees of reddish livor, but there was no evidence of swelling in the tissues. Such changes as were noted seemed identical with those seen in many individuals dying of acute

trauma out-of-doors in cold weather (Group C above). The pancreas in some cases demonstrated hemorrhagic autolysis, but this was never accompanied by any fat necrosis nor was there microscopic evidence of inflammation. Such hemorrhagic dissolution is more indicative of the postmortem interval than of pathology. Lesions in the gastrointestinal tract were limited to the stomach and included petechial hemorrhages (two cases) and petechial ulcers (one case) of the gastric mucosa.

Microscopically, none of these cases demonstrated any myocardial degeneration in the routine hematoxylin and eosin stained sections.

The observation of a colleague[3] that in hypothermic deaths the lungs are lighter than average led to a review of the pulmonary findings in this series. The combined weight of the lungs for the adults ranged from 460 to 1850 g. Ten of the cases had pulmonary weights of less than 700 g. The heavier weights were associated with pulmonary edema in all cases except one in which bronchopneumonia was present. No correlation between the etiology of hypothermia and the pulmonary weight was apparent. It was expected that the intoxicated individuals would have the pulmonary edema, but some of the victims with high blood alcohol had low pulmonary weights, while some of the people whose hypothermia resulted from mental confusion showed prominent pulmonary edema.

Discussion

Little evidence of pathology of the type described by previous investigators was found in the present series. The only gross pathology noted was gastric mucosal hemorrhage or petechial ulcers, in three cases. No microscopic lesions were apparent by routine hematoxylin and eosin stains. The discrepancy between this series and that described by Hirvonen and Huttunen [*3*] is difficult to explain. It may be due in part to the extensive special stains of the heart prepared by those authors, which enabled them to see myocardial degeneration in literally every case. Another possibility would be a difference in the rapidity of the deaths in their series compared with those in this series. I am acquainted with the lesions described in the literature. Frostbite, stress ulcers of the gastrointestinal tract, and true hemorrhagic pancreatitits have all been observed in hypothermic victims living for 24 to 72 h before succumbing to the effects of their exposure. In these more prolonged deaths, I have also observed foci of myocardial degeneration in routine hematoxylin and eosin sections. However, few gross and no microscopic abnormalities were apparent in the acute deaths reported.

The light weight of the lungs, while an interesting observation, was present in less than 50% of the series and is as nonspecific as all other autopsy findings.

In the absence of consistent and specific anatomic pathology, biochemical abnormalities are being investigated for possible supporting evidence of deaths from hypothermia. Hirvonen and Huttunen [*3*] have demonstrated an increased excretion of urinary catecholamines in such deaths compared with either natural or violent deaths. The mean urinary total catecholamine concentration was increased sevenfold over a control group of rapid violent deaths and approximately threefold over a group of sudden natural deaths. However, individual values ranged widely, and some hypothermic individuals were in the normal or control range.

The present study suggests vitreous glucose may also serve as an indicator of death from hypothermia. The data demonstrate a significant mean elevation of the vitreous glucose when compared with the control groups. Over half of the values found in the hypothermic deaths were higher than the highest glucose values in either control group, with the exception of the single aberrant value in Group B. The confidence interval of the mean for the hypothermic deaths does not approach overlapping with either of the control groups. A student t-test comparing the mean glucose values of hypothermia deaths versus both control groups yielded $P < 0.001$.

[3]B. D. Blackbourne, personal communication, Worcester, MA, 1983.

Several possible explanations for such high vitreous glucose values were investigated. First, the level of vitreous glucose for any group will depend to some extent on how soon the vitreous specimens are obtained after death because there is rapid postmortem glycolysis in all nondiabetic individuals. To compare the relative postmortem interval between several groups, the vitreous potassium may be used as an indicator, since it routinely rises with increasing postmortem time. Thus, there is a reciprocal relationship between glucose and potassium, so that the highest glucose values should be found in cases in which the vitreous potassium is the lowest. The concommitant high vitreous levels of both glucose and potassiums in the hypothermic deaths exclude the time of sampling as the explanation of the high sugar values.

Second, it was felt that rapid chilling of the body after death might prevent the usual glycolysis resulting in high vitreous glucose values. This thesis was advanced by Bray et al [*4*] as the only possible explanation for the high vitreous glucose values found in victims recovered from the water more than a week after a plane crashed into the Potomac River in Washington, DC, in January 1982. While this reasoning and conclusion appear sound for those particular cases, the same result does not appear to be true when bodies are exposed to cold air after death. This is shown in Group C of the present study, where individuals dying suddenly in frigid air showed the same low glucose values as those noted in the group where the body remained at room temperature after death (Group B). Therefore, another explanation was sought.

The literature lists hyperglycemia as a common finding in cases of hypothermia [*8, 9*]. This was supported by our own hospital data. In the 40 nondiabetic cases studied, 80% of the victims had an admission blood glucose above the upper limit of normal for our laboratory; in 12% of the cases the value exceeded 300 mg/dL. This hyperglycemia is felt to be primarily the result of elevations of serum catecholamines in response to stress. Such hyperglycemia could account for the elevated vitreous glucose values under proper conditions. Previous studies [*10*] have demonstrated that the marked terminal rise in serum glucose commonly observed in certain asphyxial deaths or in persons receiving cardiopulmonary resuscitation will not be manifested by any increase in vitreous glucose; this is recognized as a time-related phenomenon. When high serum glucose values have been present for a substantial period of time before death, there will be a corresponding elevation of vitreous glucose values as well. Some of the low values of vitreous glucose observed in the hypothermic deaths may represent cases in which a terminal rise in serum glucose occurred so close to the time of death that there was no opportunity for the vitreous glucose to be affected. Indeed, such cases may correspond to the group within Hirvonen and Huttenun's [*3*] series that had low urinary catecholamines, which they also felt to represent a time-related phenomenon. However, the low to normal glucose values found in 20% of our hospitalized group of hypothermic patients demonstrate that exposure does not invariably lead to an elevated serum glucose.

In conclusion, there were few gross and no microscopic lesions apparent by routine autopsy techniques in the acute hypothermic deaths of this series. An interesting observation was that 45% of the hypothermic deaths had low pulmonary weights. Certification of death as a result of hypothermia continues to require a proper history of exposure and the absence of some other clear-cut cause of death. Certain biochemical tests can lend supporting evidence of hypothermia. Among these may now be added the finding of a high vitreous glucose level in a nondiabetic individual.

References

[*1*] Mant, A. K., "Autopsy Diagnosis of Accidental Hypothermia," *Journal of Forensic Medicine*, Vol. 16, No. 4, Oct. 1969, pp. 126-129.

[*2*] Hirvonen, J., "Necropsy Findings in Fatal Hypothermia Cases," *Forensic Science*, Vol. 8, No. 2, 1976, pp. 155-164.

[3] Hirvonen, J. and Huttunen, P., "Increased Urinary Concentrations of Catecholamines in Hypothermia Deaths," *Journal of Forensic Sciences*, Vol. 27, No. 2, April 1982, pp. 264-271.
[4] Bray, M., Luke, J. L., and Blackbourne, B. D., "Vitreous Humor Chemistry in Deaths Associated with Rapid Chilling and Prolonged Freshwater Immersion," *Journal of Forensic Sciences*, Vol. 28, No. 3, July 1983, pp. 588-593.
[5] Coe, J. I., "Postmortem Chemistries on Human Vitreous Humor," *American Journal of Clinical Pathology*, Vol. 51, No. 6, 1969, pp. 741-750.
[6] Coe, J. I., "Further Thoughts and Observations on Postmortem Chemistry," *Forensic Science Gazette*, Vol. 4, No. 5, Dec. 1973, pp. 2-6.
[7] Coe, J. I., "Postmortem Chemistry of Blood, Cerebrospinal Fluid, and Vitreous Humor," *Legal Medicine Annual: 1976*, C. H. Wecht, Ed., Appleton-Century Croft, New York, 1976, pp. 55-92.
[8] Stine, R. J., "Accidental Hypothermia" *Journal of the American College of Emergency Physicians*, Vol. 6, No. 9, Sept. 1977, pp. 413-416.
[9] Reuler, J. B., "Hypothermia: Pathophysiology, Clinical Settings, and Management," *Annals of Internal Medicine*, Vol. 89, No. 4, Oct. 1978, pp. 519-527.
[10] Coe, J. I., "Postmortem Blood Glucose and Cardiopulmonary Resuscitation," *Forensic Science Gazette*, Vol. 6, No. 4, Sept. 1975, pp. 1-2.

Address request for reprints for additional information to
John I. Coe, M.D.
Hennepin County Medical Center
730 S. 7th St.
Minneapolis MN 55415