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Postmortem diagnosis of hypertonic dehydration

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Abstract

Beside morphological signs of hypertonic dehydration as tinting of skin, sunken eyes, dry surface of the galea or dry cutting areas of organs, a chemical profile of vitreous humor was proposed as a diagnostic tool for the diagnosis of hypertonic dehydration. The profile consists of an elevation of sodium >155 mmol/l, chloride >135 mmol/l and urea >40 mg/dl. This profile was named dehydration pattern. The value of this dehydration pattern for the diagnosis of hypertonic dehydration will be discussed by a short review of the literature and case reports. So far, the published literature on the dehydration pattern is not a sound scientific basis for the diagnosis of dehydration.

Keywords: Hypertonic dehydration; Vitreous humor; Dehydration pattern; Biochemical profile in vitreous humor

1. Introduction

A man of 70 kg bodyweight consists of 60% water, altogether 42 l. The main part of the water is found in the intracellular compartment (40% related to the bodyweight), while the interstitial and the intravasal water make up for 16 and 4%, respectively [12,13,36]. The water- as well as the electrolyte-metabolism are regulated in narrow ranges to maintain homeostasis. The loss of 15% of body water after acute and of 20% after longer lasting dehydration is lethal. Although the extracellular space makes up only one third of the whole body water, the single water spaces are regulated mainly by the extracellular fluid compartment. The regulation of the water–electrolyte-metabolism may be reversibly or irreversibly disturbed in the following ways [12,13,35]:

(1) ambient factors (hemorrhages, thirst, hot environment);
(2) diseases of the regulating organs (enteritis, renal insufficiency, burns, respiratory insufficiency);
(3) diseases of regulating endocrine organs (diabetes insipidus, Addison's disease).

However, external factors (point 1), such as the hypertonic dehydration due to liquid deprivation, the forced feeding of salt [42] or water-intoxication [40] are of the utmost forensic importance. Classical autopsy findings to substantiate the diagnosis of hypertonic dehydration are:

- poor skin turgor,
- tinting of skin,
- sunken eyes,
- dry galea and dry organ surfaces.

In the lifetime, the loss of body water results in an elevation of sodium-, chloride- and urea nitrogen-levels in blood; therefore, it can be diagnosed quite well. However, due to the postmortem loss of the selective membrane permeability a diagnosis of serum electrolytes at the moment of death is not possible [27]. Therefore, extensive investigations were carried out to make a postmortem diagnosis of vital electrolyte disturbances in vitreous humor possible [4–11]. Vitreous humor was preferred because it is topo-

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Table 1
Postmortem vitreous humor values in a reference collective (from [3])

Mean postmortem interval in hours (minimum–maximum)	1 3/4 (1/2–2 1/2)	5 3/4 (3–10)	17 1/4 (10 1/2–29)
Sodium (mmol/l)	135–151	131–151	131–150
Mean ± *s*	143 ± 0.52	143 ± 0.67	141 ± 0.76
Chloride (mmol/l)	108–132	105–132	104–130
Mean ± *s*	121 ± 0.76	119 ± 0.86	118 ± 1.16
Urea (mg/dl)	6–40	4–33	3–30
Mean ± *s*	17 ± 0.99	17 ± 0.89	18 ± 1.23

s = standard deviation.

graphically isolated and compared to other fluid compartments (e.g. serum, cerebro-spinal fluid) the diffusion is much more delayed.

2. Dehydration pattern

Coe [4] carried out extensive investigations on reference values for several constituents in vitreous humor, mainly on humans, who, prior to death, had no electrolyte dysregulation (Table 1). After having published these normal values, which were stable in the first hours postmortem, in the vitreous humor, he later on described characteristic dysregulation patterns in vitreous humor [5–7]:

- dehydration pattern,
- uremic pattern,
- low salt pattern,
- decomposition pattern (Table 2).

The dehydration pattern is characterized on the one hand by an elevation of sodium and chloride concentrations and on the other hand by an only light elevation of urea.

The uremic pattern is characterized by a severe elevation of urea nitrogen and creatinine while the concentrations of electrolytes stay more or less on a normal level.

The low salt pattern is characterized by low sodium and chloride values but it also shows a low potassium concentration (below 15 mmol/l).

In comparison, the decomposition pattern shows low sodium and chloride values, while potassium concentrations are over 20 mmol/l.

After the loss of selective membrane permeability, autolysis and diffusion cause the decomposition pattern. Since elevated urea and creatinine values are stable postmortem, the uremic pattern is of diagnostic significance; furthermore, signs of renal damage are evident at autopsy.

However, data on the diagnostic significance of the dehydration and low salt pattern have rarely been published; the literature especially lacks of information on the concentrations that cause lethality or severe illness. Although in single cases, this may be of the utmost importance.

3. Case reports in the literature[1]

After Coe had published the normal values in vitreous humor in 1969 [4], in 1972 and 1973 [5,6] for the first time he reported on the dehydration pattern. The first case reports are also from 1972:

Case 1. 75-year-old male, autopsy and subsequent toxicological investigation showed no clear cause of death. Sodium 168 mmol/l, urea nitrogen 207 mg/dl.

Case 2. 76-year-old recluse, severe hypernatremia, severe hyperchloremia, elevation of urea nitrogen.

Case 3. 43-year-old female, sodium 170 mmol/l, potassium 8.8 mmol/l, chloride 140 mmol/l, urea nitrogen 95 mg/dl.

All three cases have in common that the case reports describe no morphological signs of dehydration. A further case described sunken eyes and poor skin turgor as external signs of dehydration, while the sodium concentration found was 170 mmol/l and urea nitrogen 58 mg/dl.

Other authors like Huser and Smialek [23] reported the sudden death of children resulting of acute dehydration. In accordance with the dehydration pattern, the diagnosis was based on the history of gastroenteritis and elevated sodium and urea values in vitreous humor. Although the diagnosis of dehydration was made, the morphological signs of dehydration were missing. Instead, the authors recommend that the diagnosis of dehydration should be mainly based on the chemical findings in vitreous humor, especially when morphological signs of dehydration are missing.

A further publication on elevated sodium values and uremia as unexpected cause of death in children is from Emery et al. [16]. Among 40 cases reported by Emery et al., two fulfil the criteria for dehydration pattern according to Coe.

[1] For the identification of relevant cases the relevant international journals, mainly of forensic medicine, were looked through. Also of special help were reviews by Coe [8–10].

Table 2
Range of values of sodium and chloride by different tested methods for the dehydration pattern and low salt condition (from [10])

Vitreous humor values			
Antemortem abnormality	Flame photometry or SMA 6/60	Ektachem 400	Beckmann Astra
Dehydration			
Sodium (mmol/l)	>155	>165	>155
Chloride (mmol/l)	>135	>125	>140
Urea nitrogen (mg/dl)	40–100	40–100	40–100
Low salt condition			
Sodium (mmol/l)	<130	<135	<130
Chloride (mmol/l)	<105	<95	<110
Potassium (mmol/l)	<15	<15	<15

In 1994, Madea et al. [29] published two cases of death, due to dehydration and starvation with highly elevated sodium, chloride and urea values in vitreous humor. A further case was published by Coe [10]: a 3-year-old girl was brought to hospital by her parents. The child was dead on arrival. Although there was no anatomic evidence of dehydration, routine vitreous humor studies revealed a sodium value of 210 mmol/l, chloride 167 mmol/l and urea nitrogen 31 mg/dl. The child had been forced by the mother to eat her spaghetti dinner, which was accidentally spilled with a large amount of salt. Additionally the child had to drink a large amount of salt water.

In a further report on fatal rotavirus gastroenteritis [2], both sodium values (serum and vitreous) were mentioned to be elevated. Although a close correlation seemed to exist between the values, unfortunately they were not documented.

Table 3
Case reports in the literature with elevated sodium- and urea-values according to the dehydration pattern (cases 1–3 from Coe [5,6], 4–12 from Huser and Smialek [23], 13 and 14 from Madea [29], 15 and 16 from Emery et al. [16])

Case	References	Age	Sex	Sodium (mmol/l)	Urea (mg/dl)
1	[5]	75 Years	M	168	207
2	[6]	43 Years	F	170	95
3	[5]	1 Year		170	58
4	[23]	9 Months	F	173	53
5	[23]	8 Months	M	168	53
6	[23]	8 Months	M	163	8
7	[23]	4 Months	F	159	42
8	[23]	5 Months	M	207	45
9	[23]	13 Months	F	190	47
10	[23]	4 Months	F	157	17
11	[23]	6 Months	M	156	28
12	[23]	7 Months	M	162	29
13	[29]	2.5 Years	M	222	618
14	[29]	2.5 Years	M	180	575
15	[16]	52 Weeks		162	139
16	[16]	23 Weeks		164	196
17	[10]	3 Years	F	210	31

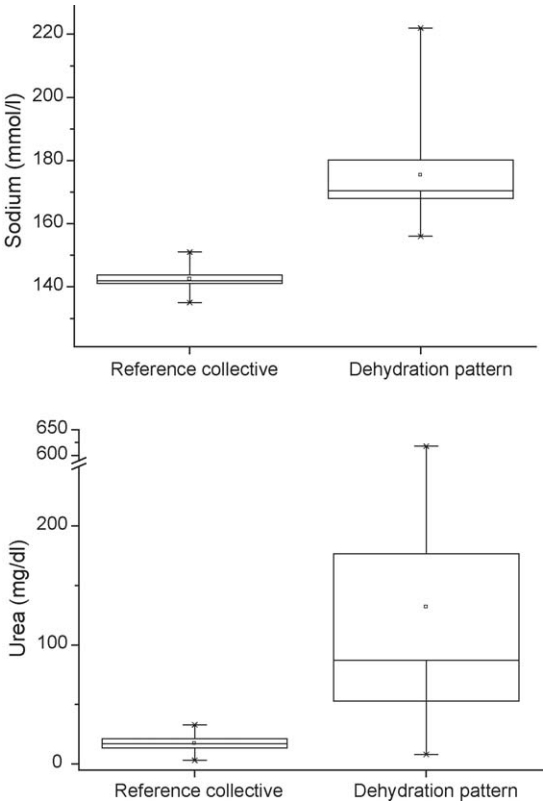

Fig. 1. Box-plots for the urea- and sodium-values in the reference cases [3] and dehydration cases (Table 3).

Altogether 17 cases were reported in the literature in which the diagnosis dehydration was made and partly based on the biochemical profile in vitreous humor (Table 3). In most cases, a complete biochemical profile according to the dehydration pattern was not available. Chloride values were missing in the reports of Huser and Smialek [23] and Emery et al. [16]. If mean values and standard deviations of these 16 cases are calculated and compared to the normal values published by Coe [4] and they are compared to the reference cases, statistically significant elevations of the analytes of the dehydration cases are of course evident (Fig. 1).

4. Discussion

Given some thought, this significance is not astonishing and does not substantiate the validity of the dehydration pattern for the postmortem diagnosis of lethal dehydration. The limit values for the dehydration pattern were chosen arbitrarily and not calculated on a study collective where the diagnosis of dehydration was based on external, independent criteria. Although according to Coe's original data [4] there seems to be a strong correlation between antemortem serum

Table 4
Own reference values in comparison to serum reference values and values reported in the literature

	Chloride (mmol/l)	Sodium (mmol/l)	Calcium (mmol/l)	Creatinine (mg/dl)
Serum reference values	98–112	134–150	2.15–2.75	0.5–1.1
Naumann (1959) [32]	89–145	118–154	0.7–1.3	0.31–1.05
Leahy and Farber (1967) [24]	108–142	128–158		
Coe (1969) [4]	104–132	131–151	1.5–2	
Own results				
Upper–lower Quartil	117–130	144.3–155.5	1.53–1.85	0.39–0.66
Med −s to Med +s	112–135	138–158	1.35–2.01	0.18–0.79
Med −2 to Med +2	100–147	128–168	1.03–2.33	–1.10

values to postmortem vitreous values for sodium and urea, other authors [3] only found a poor correlation of antemortem serum with postmortem vitreous concentrations (correlation coefficient for sodium 0.59, for chloride 0.43). Therefore, mainly in the American literature [7–11,31] recommended dysregulation patterns and reference values have to be considered with care because the reference values are very narrow (Table 4); other authors found wider ranges

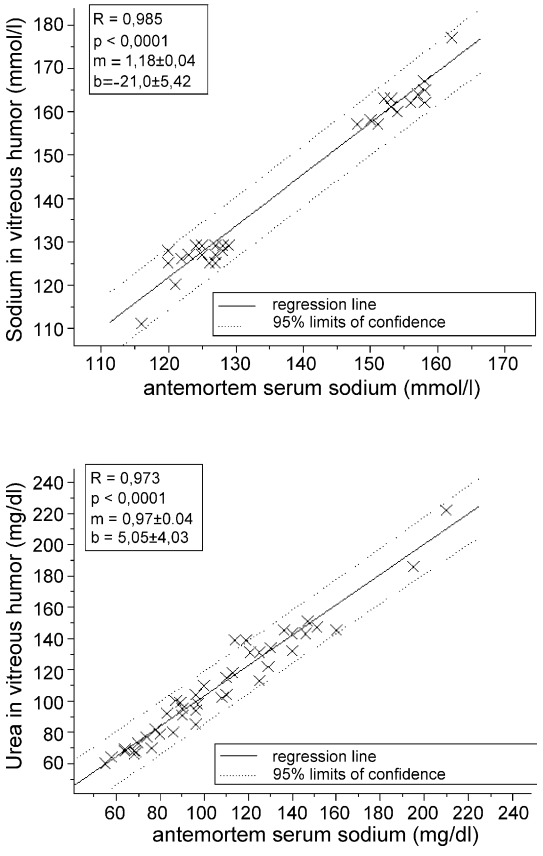

Fig. 2. Correlation between antemortem serum levels of sodium and urea and postmortem vitreous levels of sodium and urea calculated on data published by Coe [3]. Data are only available for a narrow range but not for highly elevated or depressed values.

for the different analytes [3,14,17,26,32,39,41]. Furthermore, they are not suitable as discriminating values between normal, pathologic and lethal states, because investigations on collectives with dysregulations are missing. Correlations between antemortem serum and postmortem vitreous values have only been published for a narrow range but not for highly elevated or depressed values (Fig. 2). Discriminating values can only be calculated after thorough and extensive investigations have been carried out on collectives with the diagnosis dehydration based on independent criteria [1,15,18–20,25,28,33,34,37,38]. Until now, this is not the case; animal investigations on the course of vitreous electrolytes in dehydration are also missing [21,30]. Furthermore, elevated sodium and chloride values can also be seen in other causes of death than dehydration [22] (Table 5).

Before vitreous humor values can be used as a mirror of antemortem serum values, several conceptual problems have to be analysed:

- distribution of postmortem vitreous values in comparison to serum values in vivo;
- equilibration of serum values into the vitreous humor and the velocity with which this equilibration can be achieved, either for elevated or depressed serum values;
- postmortem stability of vitreous values;
- calculation of discrimination values between ‘normal’ and ‘disturbed’ levels on defined collectives, especially of the randomized sample with disturbances.

Although these conceptual problems have yet to be solved, vitreous humor should be analysed in all relevant

Table 5
Highly elevated sodium values in other causes of death than dehydration (from [23])

Sodium (mmol/l)	Cause of death	Pre-existing diseases
186.5	Bolus death	Alcoholism
184.5	Myocardial infarction	Liver cirrhosis
177.5	Renal failure	Renal insufficiency
183	Massive bleeding	Renal insufficiency
188.5	Multi organ failure	Cancer
185	Massive bleeding	Liver disease
176.5	Massive bleeding	Unknown

cases, to use these values available in the quest for the determination of the cause of death. However, conclusions must be drawn carefully and based on a complete morphological and toxicological status. Our present knowledge does not allow us to determine a cause of death on the basis of vitreous humor values alone.

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