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Diagnosis of drowning by summation of sodium, potassium, and chloride ion levels in sphenoidal sinus fluid: Differentiating between freshwater and seawater drowning and its application to brackish water and bathtub deaths

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ABSTRACT

Analysis of ions in sphenoidal fluid can be a useful index for the diagnosis of drowning. We evaluated the reference ranges of non-drowning cases using statistical methods and three indices: sodium ion (Na^+), summation of sodium and potassium ions (SUM_{Na+K}), and summation of sodium, potassium and chloride ions ($SUM_{Na+K+Cl}$). The reference ranges were $96 \leq Na^+ < 152$, $139 \leq SUM_{Na+K} < 179$, $243 \leq SUM_{Na+K+Cl} < 311$ (mEq/L), respectively. Victim indices outside of the reference ranges indicate that the victim probably inspired water with higher or lower ion concentrations than those of body fluid in sphenoidal sinuses. Compared to the $SUM_{Na+K+Cl}$ index, the Na^+ and SUM_{Na+K} indices could distinguish among seawater drowning, freshwater drowning, and non-drowning. In drowning cases, sphenoidal fluid volume and time since death were not correlated, which suggests that water does not enter the sphenoidal sinuses after death and there is a different process for water accumulation in drowning and non-drowning cases. In bathtub cases, this method was not valid for the estimation of inspired water. Although it is necessary to observe the classical signs of drowning, this method is suitable for the estimation of drowning, especially in cases where pleural fluid or diatom tests are not available.

1. Introduction

The existence of sphenoidal fluid indicates the possibility of drowning [1]. However, the reliability of this observation remains controversial [2] because there are both drowning cases without and non-drowning cases with sphenoidal fluid.

Recently, computed tomography (CT) has been used to identify the presence of sphenoidal fluid before autopsy. However, studies on the relationship between drowning and sphenoidal fluid showed that CT imaging alone cannot be used to diagnose drowning [3–5]. In these studies, the volumes or densities of sphenoidal fluid were estimated based on CT data, but the characteristics of the fluid were not analyzed.

Diatom testing of sphenoidal fluid is also useful, but strong acids are required to perform the procedure. This method is dangerous and not simple compared to electrolyte analysis [6].

Studies have also analyzed ions in the sphenoidal fluid. Detection of chlorine (Cl) and bromine (Br) in the fluid is useful for the diagnosis of drowning [7]. There have also been studies on the differentiation between sea and freshwater drowning by the analysis of sodium (Na), potassium (K), Cl, magnesium (Mg), and total protein (TP). These studies demonstrate the usefulness of ion analysis of sphenoidal fluid [8,9]. However, special instruments may be required for measurements or combinations of concentration of various ions may be required to diagnose drowning.

We previously showed that the summation of three ions (Na, K, and Cl) in pleural fluid was useful as an index for drowning

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[10]. Only one instrument is required for this method. It is simple, allowing for diagnosis with only one index.

The current study applies this method to sphenoidal fluid. We assessed the applicability of this method in sphenoidal fluid and whether this analysis was superior to that of pleural fluid. In addition, to our knowledge, no previous report has analyzed sphenoidal fluid in cases of brackish water or bathtub drowning. Thus, this study is also the first to apply the ion analysis of sphenoidal fluid to cases found in brackish water and bathtubs.

2. Materials and methods

2.1. Subjects

The subjects included autopsy cases registered in our department from January 2014 to October 2016 within seven days of death. Facial and head injury cases were excluded from this study. We selected subjects according to the following criteria: (i) over-inflation of the lungs or froth in the air passages, (ii) positive lung diatom test findings, (iii) no penetration between the pleural cavities and outside, (iv) sphenoidal fluid, and (v) diagnosed as drowning by conventional methods. Control cases were non-drowning cases with sphenoidal fluid. We also selected drowning cases in brackish water and immersion cases found in bathtubs during the same period.

2.2. Methods

The concentrations of Na, K, and Cl ions were analyzed according to our previous report [10]. The calculated indices of water aspiration included the Na ion concentration (Na^+); the summation of the Na and K ion concentrations (SUM_{Na+K}); and the summation of the Na, K, and Cl ion concentrations ($SUM_{Na+K+Cl}$) (mEq/L). We examined the correlation between sphenoidal fluid volumes with the indices and with time since death. Multiple comparisons (Tukey's test) were performed among sea, freshwater, and control groups for each index. We estimated the cut-off values of the indices using receiver operating characteristic (ROC) curves and set reference ranges for the control cases in each index. We applied the reference ranges of each index to the subjects. This method was also applied to the brackish water and bathtub cases. The sphenoidal fluid volumes were calculated based on CT data using a workstation (Synapse Vincent; Fujifilm Medical, Tokyo, Japan). We used Excel Statistics (add-in software, Social Survey Research Information Co. Ltd., Tokyo, Japan) and Origin (Lightstone Corp., Tokyo, Japan) for statistical analysis. Differences with P values less than 0.05 were considered significant. This study was approved by the ethics committee of our university.

3. Results

The subjects included 20 cases of seawater drowning, 14 freshwater drowning cases, 11 control cases, four brackish water cases, and 11 bathtub cases. The summary and details of the subjects are shown in Tables 1–5.

The means of the three indices (Na^+, SUM_{Na+K}, $SUM_{Na+K+Cl}$) differed significantly among the seawater, freshwater, and control groups ($P < 0.05$) (Table 6). ROC analyses were performed between the seawater and the control groups and between the freshwater and the control groups for each index. The areas under the ROC curves were higher than 0.94 in all combinations of each index. The cut-off values were set using the results of the ROC analyses. We defined the reference ranges of indices with the upper limits as the cut-off values between seawater and control groups and the lower limits as the cut-off values between the freshwater and control groups. The reference ranges are as follows: $96\ \text{mEq/L} \leq Na^+ < 152\ \text{mEq/L}$, $139\ \text{mEq/L} \leq SUM_{Na+K} < 179\ \text{mEq/L}$, $243\ \text{mEq/L} \leq SUM_{Na+K+Cl} < 311\ \text{mEq/L}$ (Table 7). Index values outside of the reference range indicated that the victim might have incorporated water with higher or lower ion concentrations than those of body fluid into the sphenoidal sinus.

We arranged the case values in ascending order from the left in each index (Figs. 1–3). The Na^+ and SUM_{Na+K} indices each had sensitivities of 97% and specificities of 100%. The index of $SUM_{Na+K+Cl}$ had a sensitivity of 94% and specificity of 82%. The three indices had high sensitivities and specificities. The three groups were distinguishable according to these indices. However, the Na^+ and SUM_{Na+K} indices had higher discrimination capabilities than that of the $SUM_{Na+K+Cl}$ index.

In the brackish group, two (BR 1, 2) of the four cases were over the reference ranges while the others were within the reference ranges (Table 4).

Among 11 bathtub cases, the causes of death in two cases (BT1, 2) were asthma and stimulant intoxication. The others were diagnosed as drowning (Table 5). When we used pleural fluid for the estimation of drowning, the indices of two of nine drowning cases were within the range of freshwater drowning (BT6, 7). The indices of the non-drowning cases were not within the range of freshwater drowning (BT1, 2). In comparison, eight of the nine drowning cases were classified as freshwater drowning when $SUM_{Na+K+Cl}$ was used as an index in sphenoidal fluid (BT3, 5–11); however, the two non-drowning cases were also categorized as drowning (BT1, 2).

Although the summations of ions in the sphenoidal fluid were positively correlated with sphenoidal fluid volumes in the seawater group ($|R| = 0.3–0.5$), those summations in the freshwater and control groups were not ($|R| = 0.0–0.2$).

The sphenoidal fluid volumes were correlated with time from death in the control group ($R = 0.5$), but not in the sea and freshwater groups ($|R| = 0.0–0.1$).

4. Discussion

4.1. Comparison between sphenoidal fluid (sphenoidal method) and pleural fluid (pleural method) methods

The results showed that ion analysis of sphenoidal fluid is useful for the diagnosis of drowning.

Table 1
Subject summary.

Group	Case	Sex		Age (years)	Mean time from death (days)
		Male	Female		
Seawater	20	17	3	26–84	3.9
Freshwater	14	10	4	17–87	3.2
Control	11	7	4	22–90	2.8
Brackish water	4	4	0	39–72	2.8
Bathtub cases	11	7	4	4–98	3.0