Case Report

A Novel Practical Equation for Treatment of Emergent Hypernatremia and Dehydration Phase in Infants

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Abstract

Serum sodium (Na) concentration more than 145 mmol/L is defined as hypernatremia. Hypernatremia carries an acute morbidity and mortality, especially in neonates and infants. Rapid correction of hypernatremia leads to severe cerebral damages, and seizure is the most common neurological complication of hypernatremia. Selection and calculation of an appropriate fluid and its amount is one of the tremendous challenges. It is important to choose the correct amount of suitable fluid and adjust rehydration rate. In this study, we have suggested practical equation to determine the amount of fluid that should be administered to the neonates and infants with hypernatremia. In this equation, the amount of infusate volume will be calculated from changes in serum Na and total body water. However, serum Na and infusate Na will play an important role in equation structure, too. Our suggested equation will help physicians to manage hypernatremic dehydrated patients in a suitable manner with an adjustable rate.

KeyWords: *Dehydration, hypernatremia, infant, sodium*

Introduction

Sodium (Na) is both an electrolyte and mineral. Factors such as thirst, arginine, vasopressin, and kidneys are responsible for water homeostasis, serum sodium (Na) concentration, and serum osmolality.[1] Hypernatremia is defined as Na concentration more than 145 mmol/L. The accumulation of Na leads to the movement of water across cell membranes due to its tonicity. Accordingly, hypernatremia is always a hypertonic, hyperosmolar electrolyte disturbance and can lead to cellular dehydration.[2] Dehydration due to hypernatremia is rare but can result in serious clinical condition in newborns and infants. To maintain blood pressure in hypernatremia, water shifts from the intracellular to extracellular space. Therefore, this mechanism not only makes the infants with hypernatremia less symptomatic, but also causes more dehydration before suitable medical intervention is sought.[3] Hypernatremic dehydration is usually caused by inadequate breastfeeding, diarrhea, concentrated infant formula, and fever.[4,5] Lactation failure and low milk production are the most important factors in the development of neonatal hypernatremic dehydration.[6] Hypernatremia in newborns is associated with several life-threatening and permanent adverse effects. Seizures are the most common neurological complication. Cerebral edema, cerebral vascular accidents, paralysis, and encephalopathy are other neurologic common complications in hypernatremia.[7] Osmotic changes during treatment in the brain can exacerbate the cerebral edema and thereafter brain damage can occur.[8] In addition, infants who develop seizures during treatment require prompt anticonvulsant therapy and adequate ventilation. Regarding adverse effects of rapid correction of hypernatremia, it is important to choose correct amount of suitable fluid and rehydrate the child slowly.

In the following context, the term "hypernatremia" signifies that of "water deficit." Water deficit is the amount of free water that should be added to body to decrease serum Na concentration to the normal range. It should be noted that free water is a non-Na containing fluid.[2,9]

$$\text{Total body water (TBW)} = 0.7 \times \text{body weight (BW)} \quad \text{Hydrated neonate} \qquad (1.1)$$

$$H_2O \text{ deficit (L)} = (0.7 \times \text{BW}) [(\text{measured serum Na}/140) - 1] \qquad (1.2)$$

Considering Na concentration, total body water has to be used in equations. Although water forms 70% of BW in neonates,

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it will be different in the case of dehydration and decrease to 60% of BW.

$$TBW = 0.6 \times BW \qquad \text{Dehydrated neonate} \qquad (1.3)$$

Considering the concentration of Na in blood, intravenous fluid can be divided into isotonic and free water components. The free water is the component that can lower serum Na. Hence, the isotonic part can increase intravascular volume without changing the serum tonicity. The amount of free water in an intravenous (IV) fluid, with respect to serum Na concentration, can be determined as follows:[10]

$$\text{Free water (\%)} = 1 - (\text{IV fluid Na/serum Na}) \times 100 \qquad (1.4)$$

Table 1 shows the amount of free water for each IV solution depending on patient's serum Na concentration. As mentioned, normal saline (N/S) is not always an isotonic solution. For example, in patients with serum Na = 195, N/S is not an isotonic solution because it contains 200 mL free water in each liter, which can lower patient's serum Na concentration. In contrast, N/S is an isotonic solution in patients with serum Na concentration of 145.

Case Report

A 9-day-old breastfed boy infant was admitted to the emergency department with chief complaints of poor feeding, decreased urine output, and lethargy. In general appearance, the infant was lethargic with sunken eyes, dried mucosa, and reduced skin turgor. He had no urine output within previous 12 h. Laboratory studies disclosed the following serum values: Na: 195 mEq/L, potassium (K): 5.3 mEq/L, calcium (Ca): 8.5 mEq/L, blood urea nitrogen: 184 mg/dL, serum creatinine (Cr): 1.8 mg/dL, birth weight: 3140 g, and current weight: 2340 g (25% weight reduction within 9 days). During admission, the infant was given two bolus of 15 mL/kg N/S solution during 1 hour. After emergent phase, the serum Na became 193 mEq/L. Then, 200 ml of half saline was infused over 10 h which resulted in convulsion. At the time of the convulsion, his Na concentration was 178 (it means 17 mEq/L reductions in Na concentration during 10 h).

Treatment of hypernatremic dehydration consists of emergent and rehydration phases. In this case, both were corrected faster than standard rate. Subsequently, the infant experienced the complications of fast correction of hypernatremia. We assessed this case again and found a novel equation. This equation can be used in similar situations. In the following section, we discussed on the treatment of hypernatremia in general and in the mentioned case.

Discussion

Approach to the hypernatremic infant

Treatment of hypernatremia is performed in two phases: (1) an emergent phase with the aim of restoring intravascular volume; (2) rehydration phase with the aim of correcting serum Na concentration with an appropriate rate.[2,9] The purpose of emergent phase is to restore intravascular volume with an isotonic solution as soon as possible, which is usually carried out by administration of a bolus of 10–20 mL/kg of an isotonic solution. Restoration of intravascular volume is usually performed by administration of N/S, which is known as an isotonic solution, but not in severe hypernatremia. This fact can be of concern when N/S is administrated rapidly to restore intravascular volume.[10]

This rapid administration of a hypotonic solution can lead to serum Na decline with a rate faster than 0.5 mEq/h and can induce seizure. Subsequently, if we want to use N/S for emergent phase in a patient with severe hypernatremia, first it will be assumed isotone by adding NaCl 3%. This action not only prevents seizure but also helps intravenous fluid to remain in intravascular space, which is the main aim of emergent phase.

Equation for hypernatremia management

In rehydration phase, the purpose is to reduce serum Na with a rate of 12 mEq/day through administration of fluids. To calculate the amount of fluid, which should be given to patient with the aim of reducing serum Na by 12 mEq/mL, the following equations can be used:

$$\frac{\text{Total body Na (mEq)} + \text{total infusate (Inf) Na (mEq)}}{\text{TBW(L)} + \text{infusate volume (V) (L)}} = \text{serum (Se)}^{d}_{Na}\left(\frac{mEq}{L}\right) \qquad (3.1)$$

$$\frac{\left(Se_{Na}\left(\frac{mEq}{L}\right) \times \text{TBW (L)}\right) + \left(\text{Inf Na}\left(\frac{mEq}{L}\right) \times \text{Inf V (L)}\right)}{\text{TBW (L)} + \text{Inf V (L)}} = Se^{d}_{Na}\left(\frac{mEq}{L}\right) \qquad (3.2)$$

Where, Se_{Na}, Se^{d}_{Na} and Inf denote serum Na, desired serum Na, and infusate, respectively. Subtracting (3.2) from $Se_{Na}\left(\frac{mEq}{L}\right)$,

Table 1: Amount of free water for each intravenous solution based on patient's serum sodium concentration

Serum Na (mEq/L)	145 mEq/L		195 mEq/L	
	Isotonic %	Free water %	Isotonic %	Free water %
Intravenous fluid				
5% dextrose in water (0)	0	100	0	100
Saline 0.2% (38.5)	22	78	17	83
Saline 0.45% (77)	50	50	39	61
Saline 0.9% (154)	100	0	79	21

Na=Sodium

$$\mathrm{Se_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)-\frac{\mathrm{Se_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times \mathrm{TBW}\,(\mathrm{L})+\left(\mathrm{Inf\ Na}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times \mathrm{Inf\ V}\,(\mathrm{L})\right)}{\mathrm{TBW}\,(\mathrm{L})+\mathrm{Inf\ V}\,(\mathrm{L})}=\mathrm{Se_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)-\mathrm{Se^{d}_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right) \quad (3.3)$$

$$\frac{(\mathrm{Se_{Na}}\times \mathrm{TBW})+(\mathrm{Se_{Na}}\times \mathrm{Inf\ V})-(\mathrm{Se_{Na}}\times \mathrm{TBW})+(\mathrm{Inf\ Na}\times \mathrm{Inf\ V})}{\mathrm{TBW}+\mathrm{Inf\ V}}=\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}} \quad (3.4)$$

$$\frac{\mathrm{Se_{Na}}\times \mathrm{Inf\ V}-\mathrm{Inf\ Na}\times \mathrm{Inf\ V}}{\mathrm{TBW}+\mathrm{Inf\ V}}=\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}} \quad (3.5)$$

$$(\mathrm{Se_{Na}}\times \mathrm{Inf\ V})-(\mathrm{Inf\ Na}\times \mathrm{Inf\ V})=(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\times \mathrm{TBW}+(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\times \mathrm{Inf} \quad (3.6)$$

$$(\mathrm{Se_{Na}}\times \mathrm{Inf\ V})-(\mathrm{Inf\ Na}\times \mathrm{Inf\ V})-(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\times \mathrm{Inf\ V}=(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\times \mathrm{TBW} \quad (3.7)$$

$$\left[\mathrm{Se_{Na}}-\mathrm{Inf\ Na}-(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\right]\times \mathrm{Inf\ V}=(\mathrm{Se_{Na}}-\mathrm{Se^{d}_{Na}})\times \mathrm{TBW} \quad (3.8)$$

$$\frac{\text{Change in }\mathrm{Se_{Na}}\times \mathrm{TBW}}{\mathrm{Se_{Na}}-\mathrm{Inf\ Na}-\text{Change in }\mathrm{Se_{Na}}}=\mathrm{Inf\ V} \quad (3.9)$$

Volume of infusate needed to decrease serum Na by 12 mEq/L can be obtained using (3.9) as follows:

$$\frac{12\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times \mathrm{TBW\ (L)}}{\mathrm{Se_{Na}}\ (\mathrm{before})\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)-\mathrm{Inf\ Na}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)-12\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)}=\mathrm{Inf\,V\,(L)} \quad (3.10)$$

As it can be seen, the result stands for the amount of fluid needed to be administered during the first 24 h. Furthermore, a previous study indicated that the amount of free water required to decrease the serum Na by 1 mEq/L is 4 mL/kg for moderate (Na of 145 mEq/L) and 3 mEq/L for severe (Na of 195 mEq/L).[10] The methods of 4 mL/kg for moderate and 3 mEq/L for severe are less accurate than equation (3.9) because they did not consider the volume of infusate added to patient's volume. Equation (3.9) helps to predict the amount of IV solution according to the type of fluid and its Na content needed to decrease serum Na by 12 mEq/L. As various infusates differ in their free water content, different amounts may be needed to lower serum Na by 12 mEq/L. Our choice depends on whether or not we want to correct patient's intravascular volume in addition to normalized serum Na. To correct patient's intravascular volume, it is preferred to choose a solution with more Na content [Table 1] like N/S or half saline until the patient has received enough intravascular volume. It can be then changed to (¼) saline or 5% dextrose in water to correct serum Na. Proper choice of bolus dose both in type and amount of fluids in emergent phase will be discussed here. We proved practical aspects of equation (3.9) in rehydration phase by using it in our case condition as follows.

Choice of Fluid for Emergent Phase

Restoring intravascular volume in emergent phase is 10–20 mL/kg of NS. In the case presented here, 30 mL of NS was infused during 1 h, that is, 30 mL × 2.34 kg = 70.2 mL during 1 h. From equation (3.2), the amount of serum Na (mEq/L) can be determined, which is decreased by the bolus dose.

$$\frac{\mathrm{Se_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times \mathrm{TBW}\,(\mathrm{L})+\mathrm{Inf\,Na}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times \mathrm{Inf\ V}\,(\mathrm{L})}{\mathrm{TBW}\,(\mathrm{L})+\mathrm{Inf\ V}\,(\mathrm{L})}=\mathrm{Se^{d}_{Na}}\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)$$

$$\frac{\left(195\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times 1638\ (\mathrm{mL})\right)+\left(154\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)\times 70\ (\mathrm{mL})\right)}{1638\,(\mathrm{mL})+70\ (\mathrm{mL})}=193\left(\frac{\mathrm{mEq}}{\mathrm{L}}\right)$$

195 mEq/L – 193 mEq/L = 2 mEq/L.

The safe rate for serum Na reduction is 0.5 mEq/L/h. Hence, 30 mL/kg of N/S can cause 2 mEq reductions in 1 h in this case. It is obviously more than the safety margin rate of serum Na reduction. It is preferred to make this solution isotone to patient's serum by adding NaCl 3%. The amount of NaCl 3%, needed to be added to intravenous solution, can be calculated as follows. First, we have to determine the amount of free water, which exists in 70 ml N/S by equation (1.4).

Free water (%) = 1 − (IV fluid Na/serum Na) × 100.

Thus, 70 ml of N/S contains 14 ml free water. To change this 14 ml of free water to isotonic solution, we have to add NaCl 3% to it.

$$\frac{195}{1000}=\frac{\mathrm{Na\,(mEq)}}{14} \qquad \mathrm{Na}=2.73\ \mathrm{mEq}$$

Each liter of NaCl 3% contains 512 mEq Na:

$$\frac{195}{1000}=\frac{\mathrm{Na\,(mEq)}}{14} \qquad \mathrm{Na}=2.73\ \mathrm{mEq}$$

Therefore, 5.33 mL of NaCl 3% needs to be added to our 70 mL N/S to make it isotonic according to our patient's serum.

Choice of Fluid for Rehydration Phase

In this case, after emergent-phase intervention, the serum Na concentration was 193 mEq/L. Calculating the amount of different kinds of intravenous fluid (N/S, half saline, quarter saline, and 5% dextrose in water) that is needed to decrease serum Na by 12 mEq/L can be performed by using equation (3.10):

$$\frac{12\left(\frac{\text{mEq}}{\text{L}}\right)\times \text{TBW (L)}}{\text{Se}_{\text{Na}}\left(\frac{\text{mEq}}{\text{L}}\right)-\text{infusate Na}\left(\frac{\text{mEq}}{\text{L}}\right)-12\left(\frac{\text{mEq}}{\text{L}}\right)}\times 1000$$
$$= \text{Infusate volume (Inf V) (mL)}$$

Normal saline: $\text{Inf V} = \frac{12\ \text{mEq}\times\ 0.6\ \times 2.34}{193 - 154 - 12\ \text{mEq}}\times 1000 = 592\ \text{mL}$

Half saline: $\text{Inf V} = \frac{12\ \text{mEq}\times\ 0.6\ \times\ 2.34}{193\ -\ 77 - 12\ \text{mEq}}\times 1000 = 162\ \text{mL}$

Quarter saline: $\text{Inf V} = \frac{12\ \text{mEq}\times\ 0.6\times\ 2.34}{193\ - 38 - 12\ \text{mEq}}\times 1000 = 118\ \text{mL}$

5% dextrose in water: $\text{Inf V} = \frac{12\ \text{mEq}\times 0.6\ \times\ 2.34}{193 - 0\ - 12\ \text{mEq}}\times 1000 = 93\ \text{mL}$

At the first step of treatment, it is better to use a more hypertonic solution to provide intravascular volume. For this purpose, we can use N/S or half saline and then change to quarter saline or 5% dextrose in water. It is important to note that maintenance therapy should be started as soon as urine output has been established. We can add two fluids together or give a fluid, which is the combination of two fluids.

It is obvious that hypernatremia dehydration has been always a problem in breastfed infants and has had conflicts with different approaches of treatment. Correction of serum Na with an inappropriate rate can lead to severe complications. Selection and calculation of an appropriate fluid and its amount is challenging. Regarding the above-mentioned data, we have suggested practical equations to calculate the amount of fluid, which should be administered to hypernatremic infants both on emergent and rehydration phases. These equations can help physicians to manage the hypernatremic dehydrated infants simply and correctly.

Authors' Contributions

Mehrnoush Dianatkhah contributed in the design of the study. Azadeh Moghaddas contributed in manuscript preparation and gave revisions of the manuscript. Saba Ghaffary contributed in the conception of the study and manuscript preparation.

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Conflicts of interest

There are no conflicts of interest.

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