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Supplemental Materials for

Body sodium, potassium and water in peritoneal dialysis-associated hyponatremia

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Supplemental Appendix: Classification of true hyponatremia occurring in patients on PD

The simplified version of the Edelman formula proposed by Rose (17) is as follows:

$$[Na]_S = \frac{Na_{Body}+K_{Body}}{H_2O_{Body}} \qquad \{1\}$$

where Na_{Body}, K_{Body} and H_2O_{Body} are respectively rapidly exchangeable total body sodium, rapidly exchangeable total body potassium and total body water. By rearranging formula 1, total monovalent cation in the body is:

$$Na_{Body} + K_{Body} = [Na]_S \times H_2O_{Body} \qquad \{2\}$$

The method presented in this report has three stages, the stage of dry weight and eunatremia, the stage of hyponatremia, and the stage of interpretation of the differences between the stage of eunatremic dry weight and the stage of hyponatremia.

A. Dry Weight (DW) Stage

At this stage, body water ($H_2O_{Body,DW}$) is determined by an anthropometric formula. In this report, we used the Watson formulas (20), which have been used extensively to estimate body water in patients on PD. Normal range of $[Na]_S$ is 137-143 mmol/L. From equation 2, the eunatremic range of body sodium plus potassium at dry weight $\{(Na_{Body} + K_{Body})_{DW})\}$ is:

Lower limit:

$$(Na_{Body} + K_{Body})_{DW} = H_2O_{Body,DW} \times 137\ mEq \qquad \{3a\}$$

Average value:

$$(Na_{Body} + K_{Body})_{DW} = H_2O_{Body,DW} \times 140\ mEq \qquad \{3b\}$$

Upper limit:

$$(Na_{Body} + K_{Body})_{DW} = H_2O_{Body,DW} \times 143\ mEq \qquad \{3c\}$$

B. Stage of hyponatremia ($\downarrow [Na]_S$)

Weight (and body water) difference from the dry weight stage (ΔH_2O_{Body}):

$$\Delta H_2O_{Body} = W_{\downarrow[Na]S} - W_{DW} \qquad \{4\},$$

where W_{DW} is the dry body weight and $W_{\downarrow[Na]S}$ is the body weight in the hyponatremic stage. Formula 4 assumes that the weight change between the dry weight and the hyponatremic stages is due to a change in body water. This assumption holds routinely true for rapid (hours, few days) changes in body weight.

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Body water at the stage of hyponatremia ($H_2O_{Body,\downarrow[Na]S}$) (26-28):

$$H_2O_{Body,\downarrow[Na]S} = H_2O_{Body,DW} + \Delta H_2O_{Body} \qquad \{5\}$$

Body sodium plus potassium at the stage of hyponatremia {$(Na_{Body} + K_{Body})_{\downarrow[Na]S}$}:

$$(Na_{Body} + K_{Body})_{\downarrow[Na]S} = [Na]_S \times H_2O_{Body,\downarrow[Na]S} \qquad \{6\}$$

The value $[Na]_S$ in formula 6 is the serum sodium concentration at the stage of hyponatremia.

C. Interpretation of the differences between the stages of dry weight and hyponatremia: – Classification of hyponatremia

ΔH_2O_{Body} consists schematically of two components, an isotonic component with cation (usually sodium) concentration equal to 140 mmol/L ($\Delta H_2O_{Isotonic}$) and a pure water component (ΔH_2O):

$$\Delta H_2O_{Body} = \Delta H_2O_{Isotonic} + \Delta H_2O \qquad \{7\}$$

$\Delta H_2O_{Isotonic}$ is the volume of a solution of monovalent cation salts with a cation concentration of 140 mmol/L that is required to be infused into the body or to be removed from the body to bring $Na_{Body} + K_{Body}$ to the average dry weight sum ($H_2O_{Body,DW} \times 140\ mmol$). ΔH_2O is the additional volume of pure water needed to be removed to increase $[Na]_S$ to 140 mmol/L. The interpretation is based on the comparison of the estimates of $Na_{Body} + K_{Body}$ between the stages of dry weight and hyponatremia. Three relations of the three components are feasible:

(a) $(Na_{Body} + K_{Body})_{\downarrow[Na]S}$ is between the lower and upper limits of $(Na_{Body} + K_{Body})_{DW}$. Then:

$$\Delta H_2O_{Body} = \Delta H_2O;\ \Delta H_2O_{Isotonic} = 0\ L \qquad \{8\}$$

Water gain over the dry weight stage is the only abnormality that this combination allows (euvolemic hyponatremia). There is no excess or deficit of the monovalent cations. Removal of an amount of water equal to ΔH_2O_{Body} (or ΔH_2O) will restore eunatremia.

(b) $(Na_{Body} + K_{Body})_{\downarrow[Na]S}$ is below the lower limit of $(Na_{Body} + K_{Body})_{DW}$. Then:

$$\Delta H_2O_{Isotonic} = -\frac{(Na_{Body}+K_{Body})_{DW}-(Na_{Body}+K_{Body})_{\downarrow[Na]S}}{140}\ L \qquad \{9\}^1$$

Deficit in monovalent cations from eunatremia at dry weight {$\Delta(Na_{Body} + K_{Body})$}:

$$\Delta\left(Na_{Body} + K_{Body}\right) = -\Delta H_2O_{Isotonic} \times 140\ mEq \qquad \{10\}^1$$

This case represents hypovolemic hyponatremia and requires infusion of saline and, in case of hypokalemia, additional administration of potassium salts as the central means of its correction. The deficit of sodium plus potassium is the only mechanism of hyponatremia if $H_2O_{Body,\downarrow[Na]S} \leq H_2O_{Body,DW}$. Infusion of isotonic solutions containing a total amount of potassium plus sodium equal to the value calculated in equation 10 will correct the cation deficit. Correction of hyponatremia will require additional removal of water. Additional removal of water may be even required after correction of the cation deficit by infusion of hypertonic electrolyte solutions, particularly when $H_2O_{Body,\downarrow[Na]S}$ is equal to $H_2O_{Body,DW}$ or close to it. The deficit of electrolytes contributes to the hyponatremia, but is not its sole cause, if $H_2O_{Body,\downarrow[Na]S} > H_2O_{Body,DW}$. In this case, in addition to the infusion of an isotonic solution equal to $\Delta H_2O_{Isotonic}$, removal of a volume of water equal to ΔH_2O is also required to normalize both the amount of monovalent cations in the body and $[Na]_S$.

(c) $(Na_{Body} + K_{Body})_{\downarrow[Na]S}$ is above the upper limit of $(Na_{Body} + K_{Body})_{DW}$. Then:

$$\Delta H_2O_{Isotonic} = \frac{(Na_{Body}+K_{Body})_{\downarrow[Na]S} - (Na_{Body}+K_{Body})_{DW}}{140}\ L \qquad \{11\}^1$$

Excess in body sodium plus potassium from eunatremia at dry weight:

$$\Delta\left(Na_{Body} + K_{Body}\right) = \Delta H_2O_{Isotonic} \times 140\ mEq \qquad \{12\}^1$$

This case, in which the effect of water excess on $[Na]_S$ is tempered by a relatively smaller excess of sodium and potassium, represents hypervolemic hyponatremia. If the calculated excess of monovalent cations is large, sodium is probably the only cation retained, because even a relatively small potassium excess may be incompatible with life. Correction of the hypervolemia and hyponatremia requires removal of a volume of isotonic solution defined by equation 11, plus removal of an additional volume of water equal to $\Delta H_2O_{Body} - \Delta H_2O_{Isotonic}$.

[1]: Note: the average estimate of $(Na_{Body} + K_{Body})_{DW}$ is entered in formulas 9-12.

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