Deacon's Challenge No. 75 Answer

A man with a weight of 70 Kg was admitted in a diabetic coma with a plasma sodium concentration of 135 mmol/L and a glucose concentration of 40 mmol/L. During the first two hours of treatment with 2L 0.9% saline and insulin, he produced 2L of urine with a total sodium excretion of 40 mmol and his plasma glucose concentration had fallen to 15 mmol/L. What would you expect his plasma sodium concentration to be at this stage?

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At presentation the patient has raised plasma glucose with slightly decreased plasma sodium. As these are small molecules their concentrations will be similar throughout the extracellular (ECF) volume i.e. plasma plus interstitial fluid. The ECF will be in osmotic equilibrium with the intracellular fluid (ICF). The IV infusion has not altered the total body fluid volume since the volume administered (2L) was excreted in the urine (vol = 2L) and over a 2 h period insensible losses will be minimal (presumably there was no oral intake of fluids).

Two factors are affecting the plasma sodium *concentration*:

- The *amount* of sodium administered – most of which remains in the ECF
- *Redistribution of water* between the ECF and ICF compartments so as to maintain osmotic equilibrium

Step 1: Calculation of the sodium load (in mmol)

Na^+ given = 2 L of 0.9 % NaCl = 2 L of 9 g/L NaCl = 2 x 9 = 18 g NaCl

MW NaCl = 23 + 35.5 = 58.5

mmol NaCl (= mmol Na^+) given = $\frac{18 \times 1000}{58.5}$ = 308 mmol (3 sig figs)

Na^+ gain by ECF = Na^+ given - $Na^+_{excreted}$ = 308 - 40 = 268 mmol

Step 2: Calculation of the effect of water shifts between the ECF and ICF

The sodium administered to the circulation will become evenly distributed throughout the ECF. As a result the osmolarity of the ECF rises in excess of that of the ICF and water shifts by osmosis from the ICF to the ECF in order to maintain osmotic equilibrium. The effect of this is to *lower* the expected increase in ECF osmolarity due

to the saline infusion. Once equilibrium is established the osmolarity of both compartments must be identical so the increase in osmolarity due to the administered saline must also be the same. Consider both compartments (ECF + ICF) together:

Body is approx 60% water, so 70 Kg man contains approx $\frac{70 \times 60}{100}$ = 42 L water

Use the total sodium administered and the total body water volume (ECF + ICF) to calculate the increase in sodium concentration (or its osmotic equivalent in the ICF):

$$\Delta\ Na^+ \text{ due to saline administration} = \frac{\text{Total } Na^+ \text{ load (mmol)}}{\text{Total body fluid (ECF + ICF) vol (L)}}$$

$$= \frac{268}{42} = 6.4 \text{ mmol/L (2 sig figs)}$$

Similarly lowering plasma (and ECF) glucose by insulin therapy decreases ECF osmolarity relative to that of the ICF so that a further shift of water occurs but in the *opposite direction* i.e. from ECF to ICF, which will have the effect of *concentrating* plasma sodium. First calculate the total osmotic load (which will be negative) achieved by reducing plasma glucose :

Osmotic load = Δ plasma glucose (mmol/L) x ECF vol (L)

One third of body water (42 L) is in the ECF so that the ECF volume = 42/3 = 14 L

Therefore osmotic load = (15 – 40) x 14 = (-25) x 14 = - 350 mmol

Again once osmotic equilibrium is established the osmotic concentration in each compartment is identical so that the decrease in osmotic concentration in the ECF and ICF is also the same and can be calculated from the osmotic load and the total fluid (ECF + ICF) volume:

$$\Delta \text{ osmolarity} = \frac{\text{Total osmotic load (mmol)}}{\text{Total body water (L)}} = -\frac{350}{42} = -8.3 \text{ mmol/L (2 sig figs)}$$

Lowering the plasma glucose by 25 mmol/L has only reduced the plasma osmolarity by 8.3 mmol/L. Therefore the concentrations of other ionic species (mainly sodium and its association anions) must have *increased* by the difference between these two values:

Δ Na^+ (+ anions) concentration = Δ osmolarity (mmol/L) - Δ plasma glucose (mmol/L)

= - 8.3 - (-25) = 16.7 mmol/L

and the change in Na^+ is one half of this i.e. 16.7/2 = 8.4 mmol/L (2 sig figs)

The expected final plasma sodium concentration will be the sum of the initial value and the increases due to both saline administration (which is less than expected from the sodium load due to an osmotic shift of water from the ICF to ECF) and to the fluid shift which resulted from the lowering of plasma glucose:

Final plasma Na^+ concentration = 135 + 6.4 + 8.4 = **150 mmol/L** (3 sig figs)

NB:
It is possible to calculate the change in sodium concentration in a single step:

$$\Delta Na^+ = \frac{Na^+ \text{ load (mmol)} + [-\Delta \text{ plasma glucose (mmol/L)} \times \text{ECF vol (L)}]}{\text{Total body fluid vol (L)}}$$

$$= \frac{268 + (25 \times 14)}{42} = \frac{618}{42} = 15 \text{ mmol/L (2 sig figs)}$$

Question 76

The following results are generated on an adult male from a blood sample and a urine collection stated to be of 24-hours duration:

	Serum	Urine
Sodium	144 mmol/L	72 mmol/L
Creatinine	92 µmol/L	2.1 mmol/L
Calcium	2.95 mmol/L	3.1 mmol/L
Phosphate	0.74 mmol/L	12.1 mmol/L
Volume		520 mL

On the basis of these data calculate:

a) Calcium excretion per 24 hours
b) Calcium filtration per minute
c) Fractional excretion of calcium

Comment on the validity of these results.

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