THE STORY OF SALTY SAM

Understanding fluids, urea and electrolyte balance; a quantitative approach.

A self-directed learning activity. Part One.

MEET SALTY SAM

Salty Sam is a pretty average 70 kg bloke, and the guy at the gym told him that 60% of his body mass is water. (The guy at the gym has a machine that just measures electrical impedance between two points on the body and then calculates the percentage of water which would cause that impedance).

- How many litres of water are in Salty Sam?

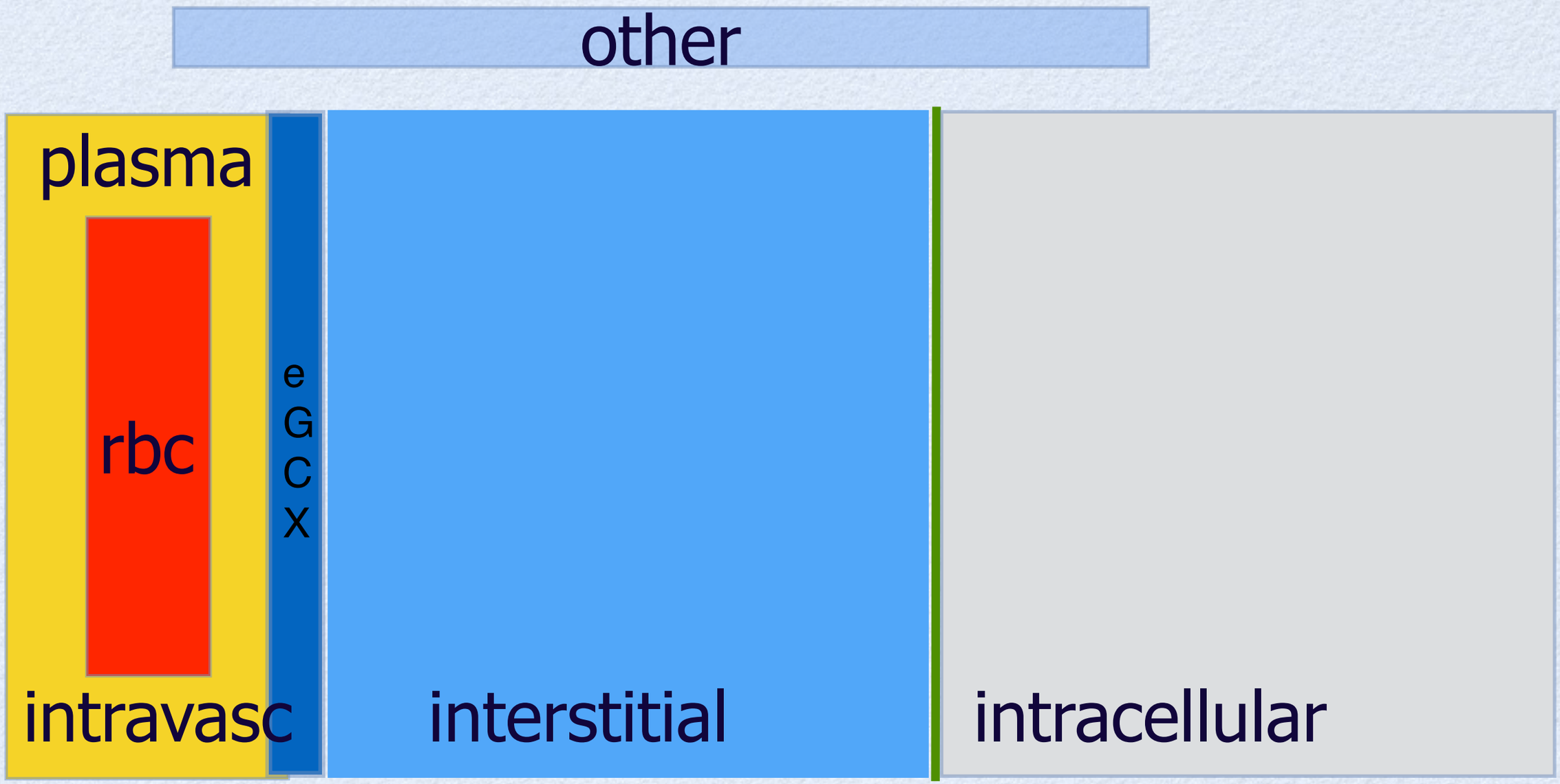
Well done if you calculated correct answer 42 litres. (Sam is 60% of 70 kg water, therefore 42 kg water, and you know from school that a litre of water has a mass of 1 kg.)

- If Sam is 25% extra cellular fluid (ECF), what (rounded to whole litres) are his ECF and his intracellular fluid volumes?

We'll say ECF = 17 litres, ICF = 25 litres for that total body water of 42 litres.

Let's see a diagram of the watery compartments of Sam's body, and note that the intravascular space has both ECF (plasma) and ICF (cells and platelets) components.

BODY FLUIDS



Glycocalyx and Interstitial are the gel phases of ECF

The intravascular space is separated from about 12 litres of interstitial fluid (which is part of the ECF) by flat endothelial cells. Capillaries are permeable to water and smaller molecules and ions, but keep cells, platelets and molecules bigger than about 65,000 Daltons intravascular.

The interstitial fluid is separated from 25 litres of intracellular fluid by cell membranes, which consume ATP as they pump sodium out to the ECF, while potassium leaks in. This process generates a membrane potential which is essential to nervous system function, muscular activity, and life itself.

- Look at the plasma U&E of a ‘well’ patient, maybe a pre-op result. Ignoring albumin, which is concentrated in the intravascular volume, which are the six most numerous ions and molecules in ECF?

Your answer should include sodium (about 138 millimol l^{-1}), chloride (110), bicarbonate (25), potassium, glucose and urea (about 4 each). Don't be mislead by the big numbers for creatinine and bilirubin, these are MICROmolar concentrations

These six molecules are the major contributors to plasma and ECF osmolality. Indeed, you can make a pretty reliable estimate of plasma osmolality by adding 2x the sodium concentration (for every cation, there is an anion) to the glucose and urea concentrations;

- Na 137, K 4.5, Urea 6, Glucose 5; estimate plasma osmolality.

If you answered 285 mosmol l^{-1}, you've got the idea.

Now it happens that the hypothalamic/ pituitary/ adrenal team actively maintain osmolality of the body water at about 275-295 mosmol l^{-1} in health, but the major anions and cations of ECF and ICF differ substantially.

- Study the next slide...

SOME SOLUTE CONCENTRATIONS.

A- IS THE IONIC 'EQUIVALENCE' OF WEAK ACIDS (PROTEINS, PHOSPHATES ETC)

	isf	**plasma**	**rbc icf**	**icf**
vol/70kg	*14*	*3*	*1*	*24*
Na	135	140	19	10
Cl	110	105	50	10
K	3	4	95	155
A^-	-	15	42	115
Mg	2	2	5	10
Other anions	1	1	10	35
Bicarb	30	25	15	12
pH	7.4	7.4	7.2	7.0

Among the ICF / ECF differences you will have noticed, the most obvious is that potassium is the predominant intracellular cation, and recall that the daily requirements for potassium and sodium in health are similar. The interstitial fluid is the largest portion of ECF, and it's chemistry is similar to that of plasma with exception of "anion A" (mostly albumin in plasma).

The guy at the gym told Salty Sam that the recommended daily allowance of sodium chloride in the diet was up to 6 g, and that more than this could lead to high blood pressure and heart failure.

- What volume of 0.9% sodium chloride solution equates to 6 g NaCl? How many mmol Na in 6 g NaCl?

- If you answered 670 ml and 100 mmol (or there abouts) you don't need the explanation below!

  0.9% NaCl is 0.9 g in 100 ml, therefore 9 g in a litre, or 6 g in 667 ml. At 155 mmol l^{-1} of sodium and of chloride, two thirds of a litre contains a little over 100 mmol, the RDA of sodium chloride. We see that we need a good reason to prescribe a patient more than a litre a day of saline, whether "normal" or "balanced".

With a healthy diet, Salty Sam takes in fats, carbs and proteins which he metabolises to carbon dioxide (excreted via the lungs) and ammonia, which his liver converts to urea and his kidneys excrete in urine. Sam makes and has to excrete upwards of 500 mmol urea per day.

As well as 500 mmol urea and 100 mmol sodium, Sam has to excrete about 200 mosmol of other ions making about 800 mosmol per day.

- With a total water intake of 2500 ml, and insensible loss of about 500 ml, how much urine does Sam pass per day, and what is its osmolality?

Hope you found this one simple. 2500-500 = 2000 ml urine containing 800 mosmol urea and ions and so about 400 mosmol l^{-1}. Also observe urinary sodium concentration about 50 mmol l^{-1}.

- On holiday in a hot desert, Sam is limited to only 2 litres of water and his insensible loss doubles to 1000 ml; what is his urinary volume and osmolality going to be?

One litre, 800 mosmol l^{-1}. Too easy.

The maximal urinary osmolality Sam might achieve in health is no more than 1200 mosmol l^{-1}, so he might be able to get by on a daily urine volume of about 800 ml (30 ml per hour), but not much less. For this reason, a urine output less than 120 ml in any four hour period deserves careful assessment and treatment.

Easy. And we note the importance of knowing and considering the daily volume inputs and outputs, not just hourly values.

- On his birthday, Salty Sam drinks 6 pints of 6X (about 4 litres of 4% alcohol) on top of his healthy 2.5 litre diet. What urine output do you expect?

6 litres of dilute urine (800 mosmol in 6 litres is about 130 mosmol l^{-1}) after allowing for 500 ml insensible loss. But what about the alcohol? What Sam does not metabolise will add an osmolar load which will increase his urine output further, dehydrate him and give him a hangover next day.

Salty Sam was admitted to Middleton-on-Sea Infirmary for a hemicolectomy...

Made NBM so Dr Eugene prescribed 'maintenance' Hartmann's at 100 ml per h plus "cef and met" tds. Anaesthetist gave a litre of Hartmann's to prevent epidural-induced hypotension, and a further two litres during the op. In HDU, he was given a fluid challenge of 500 ml gelofusine for oliguria (<30 ml per h) and hypotension (<90 mmHg sys).

- How much urine and how many osmoles should we expect Sam to excrete?

You needed to know that Hartmann's contains 131 mmol l^{-1} sodium; his sodium load from this was therefore (5.4 x 131 =) 700 mmol. Gelatine solution contains sodium 150 mmol l^{-1}, therefore (0.5 x 150 =) 75 mmol. Finally, three doses of cef & met are 300 ml water and sodium 75 mmol. Totals 6.2 litres water and 850 mmol sodium.

You need to allow for greater insensible loss, say about 1000 ml on day of laparotomy. And Sam continues to produce 500 mmol urea and 200 mmol other ions. You would therefore expect 5.2 litres of urine with osmolality about 300 to maintain balance.

But people like Sam usually produce only about 1200 ml urine on the first post-op day, and its osmolality rarely exceeds 600 mosmol l^{-1}.

- Why is this, and what are the consequences of our very liberal crystalloid prescription?

Why? Trauma response includes ADH/ vasopressin rise (water reabsorption from the renal collecting ducts) and renin/ angiotensin/ aldosterone activity (sodium reabsorption from the distal tubules).

Consequence of liberal crystalloid therapy? Body water increased by 4 l and sodium by 750 mmol, with ECF increased to 21 l.

FLUID OVERLOAD

Most cases of "ARDS" are fluid overload; in one large study of early sepsis, "ARDS" only occurred when preceded by positive fluid balance and hypoalbuminaemia. In a study of perioperative fluid therapy, a weight gain >4 kg was associated with increased risk of various complications including atelectasis, pyrexia, SIRS, pneumonia, wound infection and dehiscence.

Fluid overload can present as cardiac arrest with no preceding indications of oedema. In a recent case, a Pathologist gave “fluid overload” as the cause of a young patient’s death after orthopaedic surgery, leading to a Coroner’s Inquest. Fluid overload is an avoidable iatrogenic disease.

Let's see if Dr Eugene can do better second time round. "Maintenance" is not a bad idea if prescribed appropriately. How about 1 ml kg^{-1} h^{-1} of Dex 5% with 1/5 normal saline? That's 70 ml h^{-1} for Sam. And let's give some potassium rather than wait for it to fall, maybe 20 mmol l^{-1} in each bag.

- What is the daily salt & water provision for this prescription? With "cef and met"?

(70 x 24=) 1680 ml of water with 50 mmol sodium and 34 mmol potassium.

Three doses of cefuroxime 1.5 G contributes further 30 mmol sodium, and three doses of iv metronidazole 45 mmol sodium, total 75 mmol Na in 300 ml water.

The informed anaesthetist knows that "fluid loading" does not prevent anaesthesia-induced hypotension in a patient with normal blood volume, so let's see if Dr Eugene can persuade him to use no more than two litres of Hartmanns intraoperatively, unless blood loss exceeds 10% blood volume.

Total so far is water 4 l, sodium 385 mmol. That should be enough for Sam to produce 1300 ml urine of 600 mosmol l^{-1} carrying 800 mmol of urea and electrolytes. With an insensible loss of about 1000 ml, his 24 hour balance will be just 1700 ml water and up to 285 mmol sodium positive. This modest expansion of Sam's ECF on the day of surgery should not be harmful.

If bleeding (loss of intravascular volume) is believed to be causing hypotension, test response to isotonic salt solution resuscitation.

REFLECTIONS ON WATER...

- Fluid overloading is an avoidable iatrogenic disorder which manifests as ECF volume expansion.
- You must be aware of daily water and sodium balance in your patients.
- Remember that stress limits urine volume, and that urea takes up at least 500 of daily osmolar renal excretion.
- It helps to know urine sodium and osmolality!