Physiology | Lecture 13

Body Fluids pt.1

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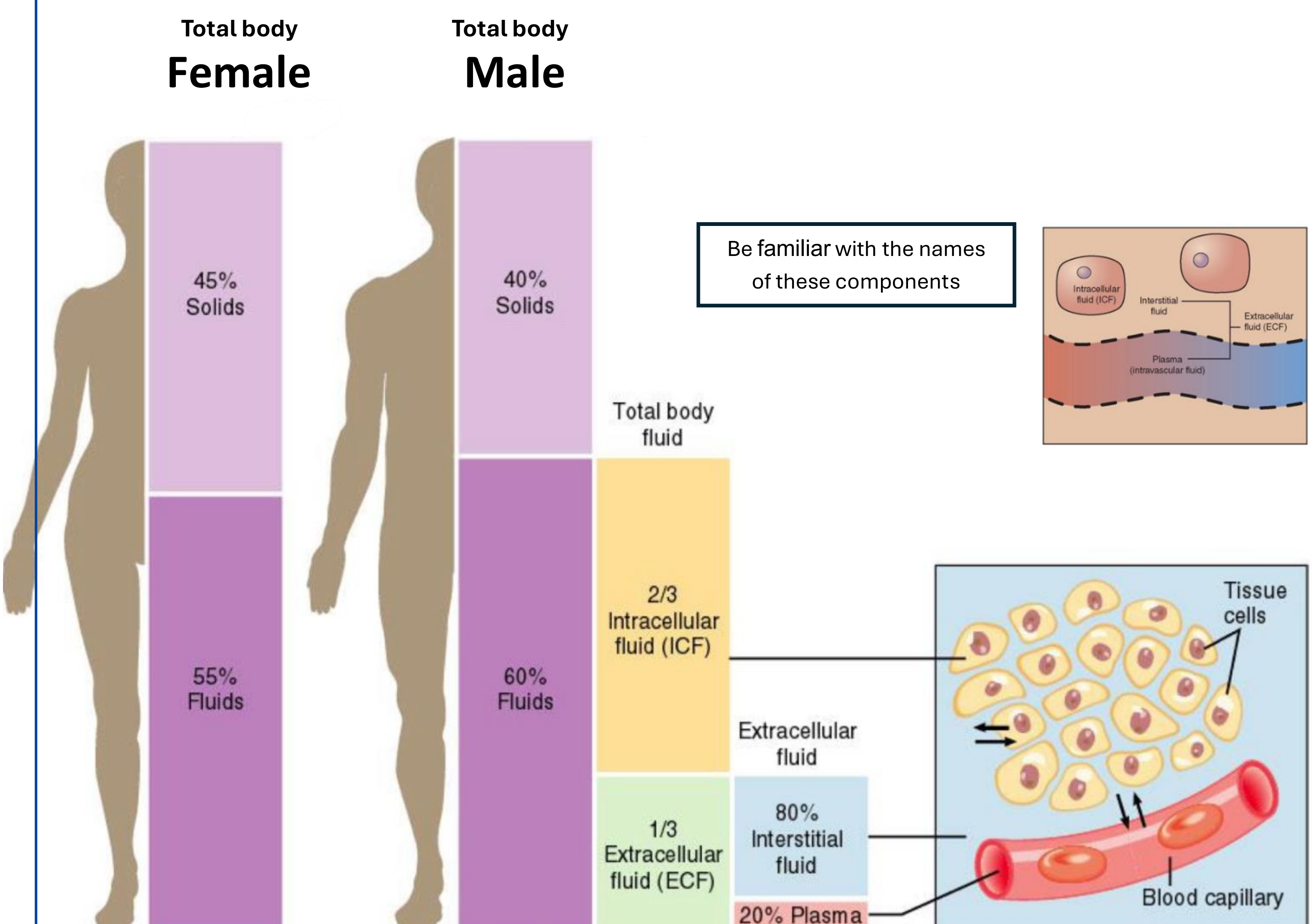
Body Fluids

Fluid compartments

The total body fluid is distributed mainly between two compartments:

the extracellular fluid (ECF) and the intracellular fluid (ICF).

The following figure shows the fluid compartments in our body:

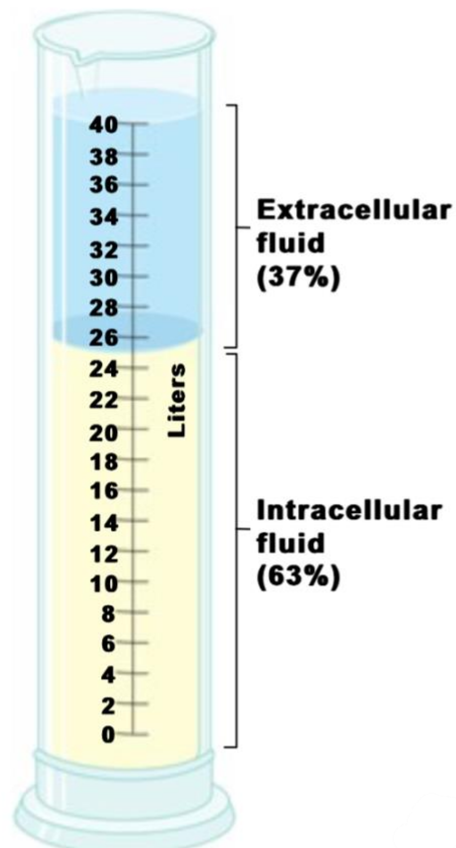


(a) Distribution of body solids and fluids in an average lean, adult female and male

(b) Exchange of water among body fluid compartments

The extracellular fluids are constantly mixing, so the plasma and interstitial fluids have about the same composition except for proteins, which have a higher concentration in the plasma.
As you see here, you may find some differences on the number, but don't worry about it, you know we have about 60% of our weight composed of water 2/3 inside & 1/3 outside.

- Of the 40 liters of water in the body of an average adult, about two-thirds is intracellular fluid and one-third is extracellular fluid
- An average adult female is about 52% water by weight, and an average male about 63% water by weight

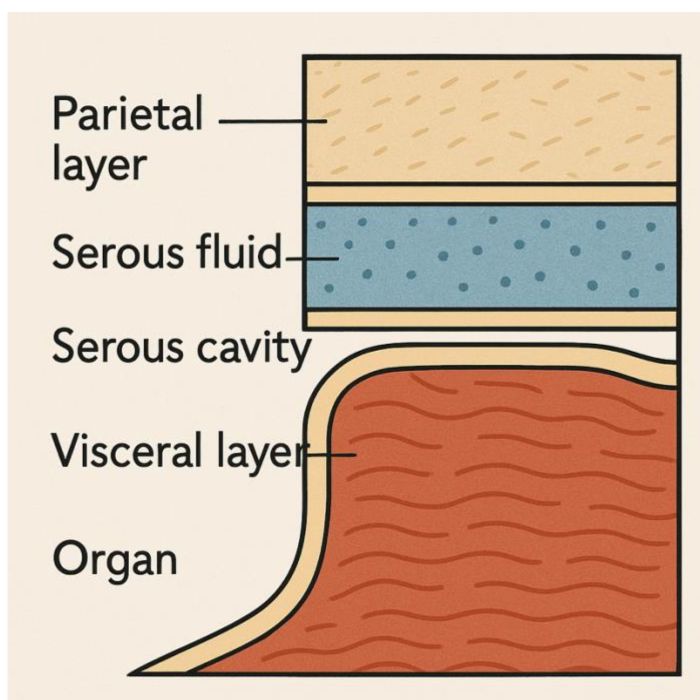


Water Distribution

You know we have a lot of cavities in our body like chest cavity, abdomen cavity and so on. In these cavities we can see one line serous layer and also another layer (**which envelops the organs**), between the two layers we have small space which forms cavity, and in that small space we have small amount of fluid which is important for the frictions that happen when you have troubles during movement or when your heart is pumping.

Imagine this for more understanding (a simple breakdown **not from the doctor**) :

- You have a body cavity (like the thoracic cavity).
- The cavity is lined by a serous membrane, which has two layers:
    1. **Parietal layer** – lines the inner surface of the cavity.
    2. **Visceral layer** – covers the organ itself (like the lungs, heart, etc.).
- Between these layers is a very thin potential space — the **serous cavity** (pleural, pericardial, or peritoneal depending on the location).
- That space contains a small amount of **serous fluid** to reduce friction during movements like breathing or the heart beating.



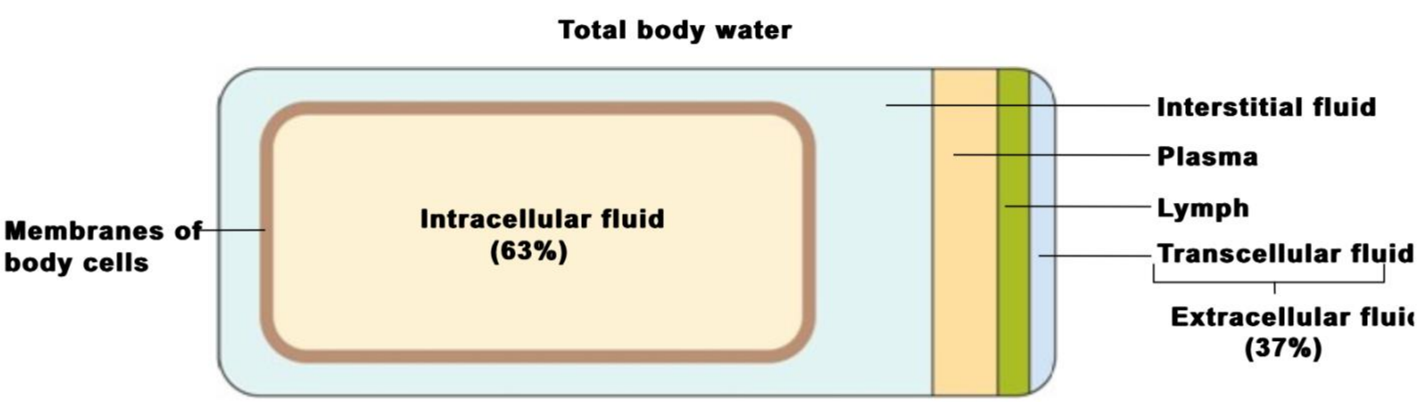
These fluids are considered to be **transcellular fluid** compartments, we have many transcellular fluids such as:

1. **Synovial** (forming around the joints).
2. **Pericardial** inside (around the heart).
3. **Pleural** inside (around the lungs).
4. **Peritoneal** (in the abdominal cavity).
5. **Ocular** inside your eye.
6. **Cerebrospinal** around neural tissue in the CNS (brain and cord).

Transcellular fluids: the portion of the total amount of body fluids contained epithelial lined spaces.

Here you can see the water distribution of our body fluids:

Plasma: is the intravascular fluid part of the extracellular fluid.

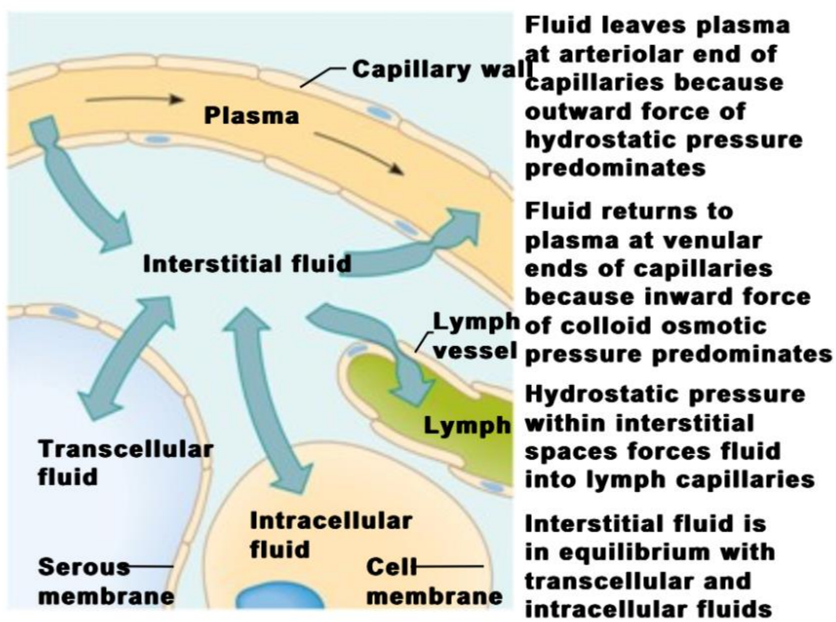


Movement of Fluids between Compartments

Now the question is, are these fluids static? Of course not, all the time we have exchange of water, nutrients and other materials, so we have movement between the sub compartments according to the pressure differences in our body.

- The major factors or that regulate movement are osmotic pressure, hydrostatic and colloid pressure (**oncotic pressure**) caused by proteins.

- Two major factors regulate the movement of water and electrolytes from one fluid compartment to another
  - Hydrostatic pressure
  - Osmotic pressure



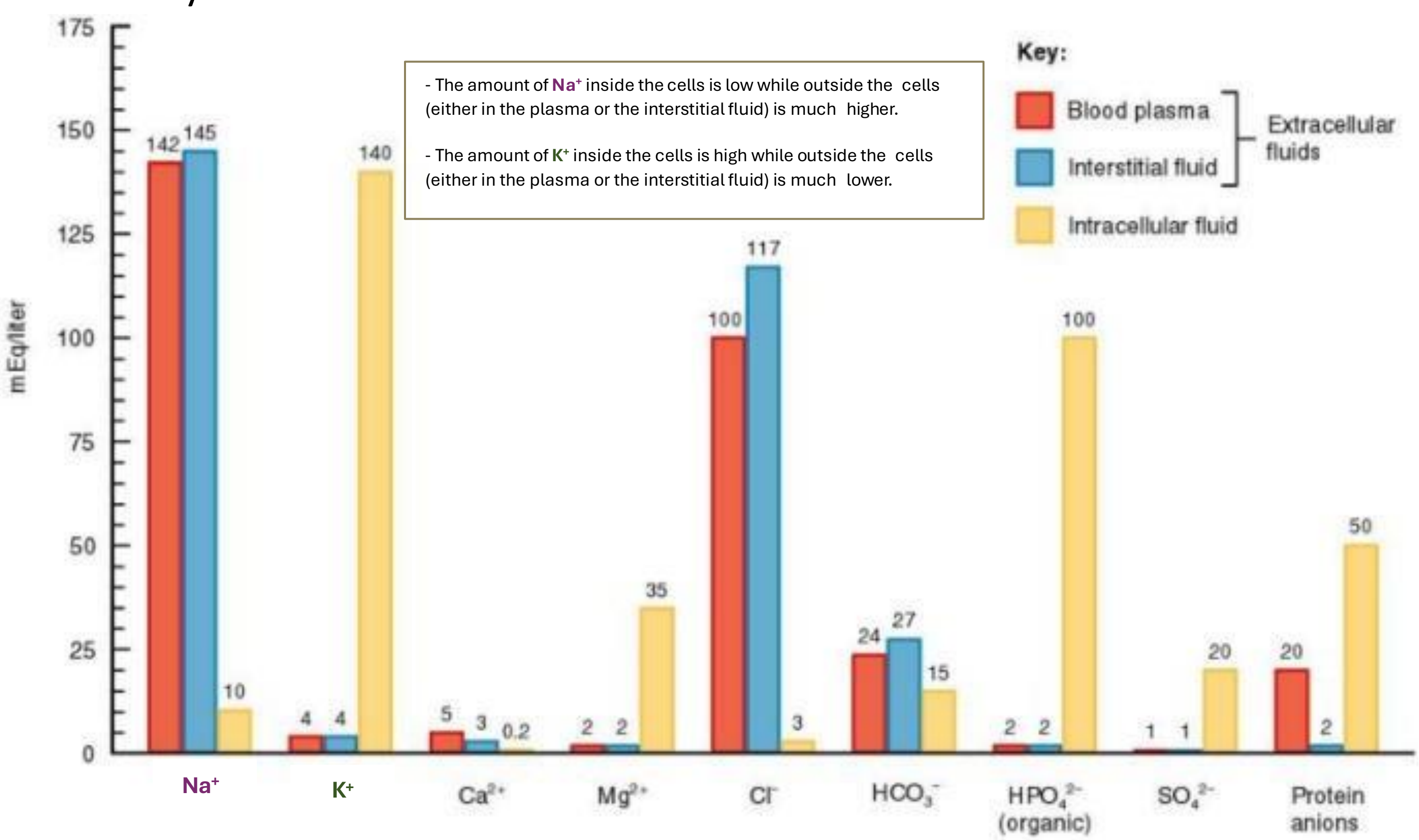
Composition of Body Fluids

Do we have the same composition of body fluids?

No, if you have been attention to the ECF (**the blood plasma and interstitial fluid**) you will find small differences between them, but regard to protein -**as in the following diagram**- there is much higher amount of it in plasma than in the interstitial fluid.

The absorption of fluids we are getting by the high colloid pressure that created is resulting from the absorption of fluids at the capillary wall, the capillary pulls the fluids from the interstitial fluid toward the plasma.

As you see in the diagram, we have differences in the composition of body fluids in the ECF and ICF.



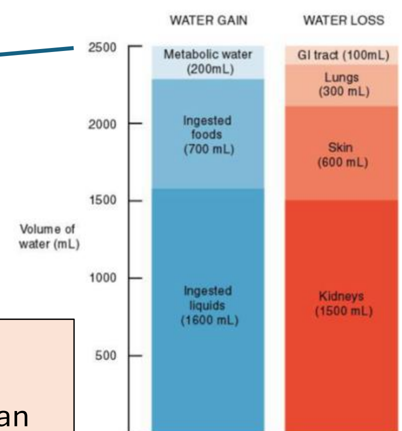
Water Balance

All the time we are drinking water and releasing it from our body, the amount of water we are getting and the amount of water we are losing are in balance all the time, but what do we mean by balance?

Balance means that "**<u>the amount of water gain or loss is the same all the time</u>**". As you can see in the figure bellow (**water gain** = **water loss**), we have that because in our body there is powerful system (**that control the homeostasis of water**) and other determinants as osmolarity (**which is very important to keep the amount of water constant**).

Constant volume of water in the body → controlled volumes → by controlling osmolarity which is determined by sodium ions (ECM ions concentration regulation of theses ions)

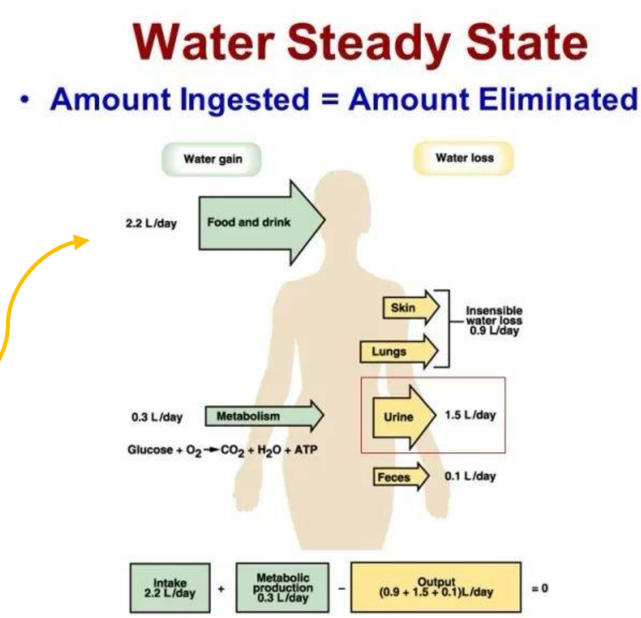
Don't forget the amount of water gain or loss is about 2500 ml/day.



In any given body -all the time- water is in a balance ..

So if here is any increase in water output (by more loss of water), there will be an increase in water input

-والعكس صحيح- to keep that balance .



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Water Inputs

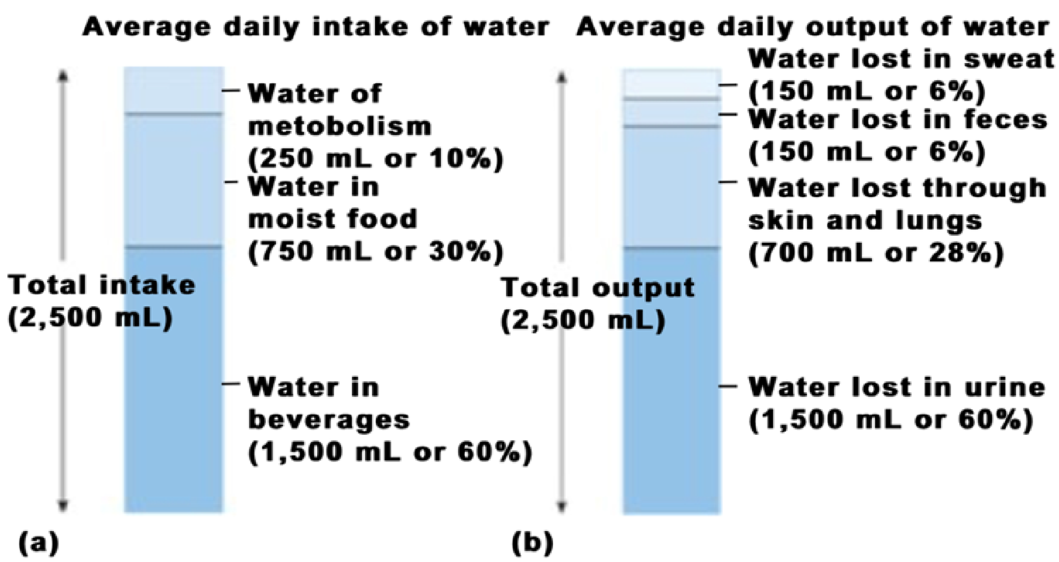
The volume of water gained each day varies among individuals averaging about 2500 millimeters daily for an adult:

- 60% from drinking.
- 30% from moist foods (**You don't just eat totally dried food, you eat food which is wet too**).
- 10% as bi-products of oxidative metabolism of nutrients called water of metabolism.

Water Output

Water normally enters the body only through the mouth, but it can be lost by variety of routes including:

- Urine (60% loss)
- Feces (6% loss)
- Sweat "sensible perspiration" (6% loss)
- Evaporation from the skin "insensible perspiration" and from the lungs during breathing 28%.



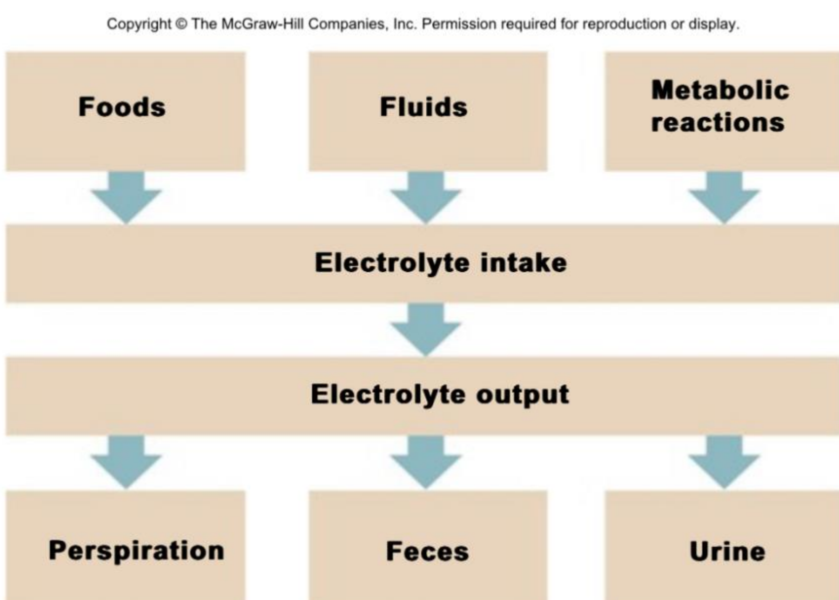
We have sensible and insensible loss of water in the body, sensible is what we are sensing, when you are sweating you sense this sweat, but when the water evaporation from your skin you won't sense it and that's an example of what we call the insensible loss. Also, the respiratory tract during respiration loss water which is another example of insensible loss of water.

Water and Electrolytes Homeostasis

We have a lot of systems in our body which are involving in keeping homeostasis, the regulation of these fluids and electrolytes such as:

Remember: fluids and electrolytes are not static, we have exchanged all the time

- Kidneys.
- Cardiovascular system.
- Endocrine which has a lot of glands involve (Pituitary, Parathyroids, Adrenal glands).
- Lungs, they are involved in a way or another in keeping homeostasis.
- Skin.



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Regulation of Na^+ and Water

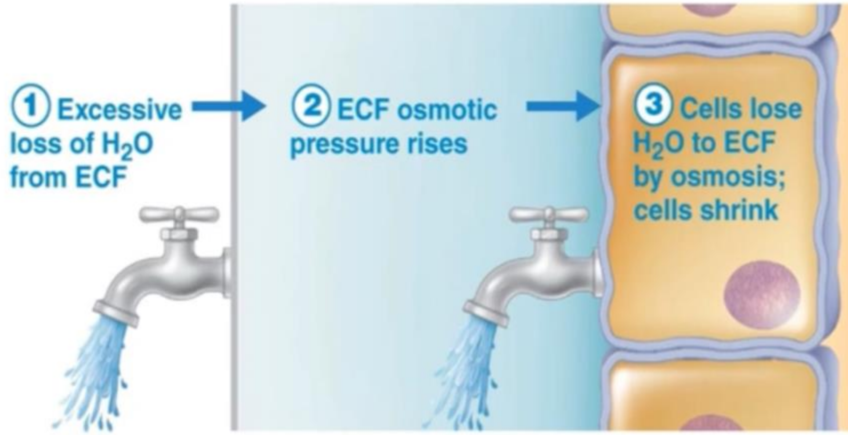
Regulation of Na^+ and water involves:

- Osmolality.
- Volume of ECF.
- Different regulations with many overlapping mechanisms.

- You can regulate volume by regulating osmolality and you can change the osmolality by changing volume

Let's say there is loss of water from the ECF, what will happen to the osmolarity of the ECF?

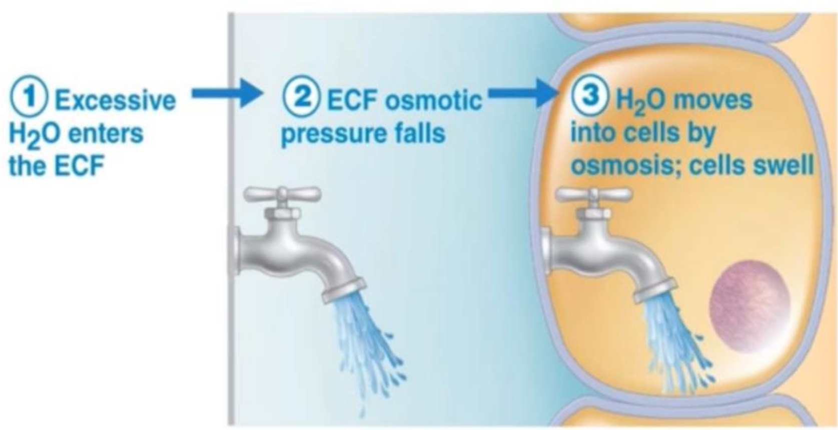
It will increase which will attract water from the inside of the cells that will make it shrink (dehydration of cells). (Look at figure a)



(a) Consequences of dehydration. If more water than solutes is lost, cells shrink.

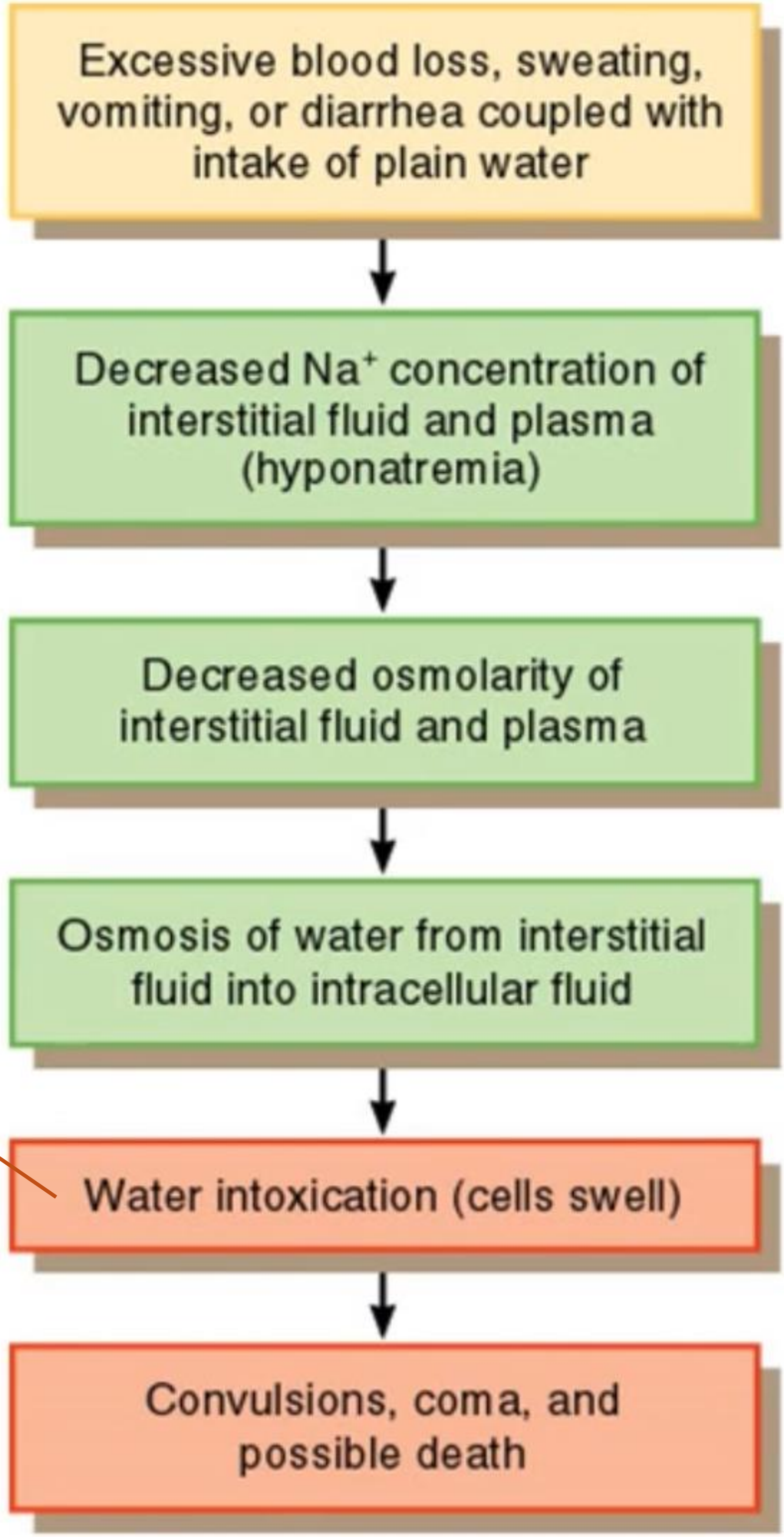
Now what will happen if we gain water more than necessary?

That will lead to water intoxication (**water becoming toxic**), the osmolarity of the ECM will decrease and water will shift from extracellular fluid toward intracellular fluid which makes the cell swelling. (Look at figure b)



(b) Consequences of hypotonic hydration (water gain). If more water than solutes is gained, cells swell.

You have some tissue which are sensitive to the changing of the body fluids, such as the brain tissue.



The most sensitive tissue for this case is the neural tissue (found in brain, spinal cord and nerves), since neurons control a lot of functions this may cause serious effects such as convulsions, coma and may lead to death; because this effects other functions like cardiovascular functions.

Movement of body fluids

- Interstitial fluid is very similar to plasma:
- Now imagine the plasma with all it's components, and you've filtered it from proteins and protein-bound substances, just like that, eventually you will have the interstitial fluid.

- if you take one liter of the extracellular fluid, then all cations and anions together will produce osmotic power to hold water , this equals about 290 osmole per that liter of water, and this is the normal osmolarity in the human body fluid, of course main contribution is done in the exotic by sodium and chloride.

And so if anyone asked you about the osmolarity of pure water, you better answer him immediately: zero, there is no osmotically active particles in pure water, the amount of water in any compartment is proportionate to the number of osmatically active particles, which are the solutes that can't pass a given semi-permeable membrane, in fact, fluids love to be with solutes, (you can revise osmosis from past lectures for further understanding).

- I think you already know that cells are bags of potassium ions, so the major component of the intracellular fluid is K+, and obviously Na+ is the major component of the extracellular fluid.

- keep in mind that the biological partition between plasma and the interstitial fluid is the capillary membrane, and capillary membrane is very permeable and so it doesn't offer any barrier to the movement of sodium and chloride, because capillary membrane is highly porous (has a lot of pores), that means: sodium and chloride concentration will be always equal in plasma and in the interstitial fluid, the opposite case related to cell membrane which doesn't allow sodium chloride to move freely, now why is this so important? Go ahead and read the following:

- Now imagine that there is a high concentration of sodium chloride in an extracellular compartment, sodium will not be able to enter the cells, and it will concentrate outside, due to that, osmotically active particles will be more outside the cell (it's hyperosmolar outside) then in this case plasma of the blood will become more salty, and there is a high osmotic pressure in the extracellular fluid, so the solute in the extracellular will drag the water toward itself, remember: water move from hypotonic to hypertonic (from low effective osmotic pressure to high effective osmotic pressure).
- Now imagine that you have eaten a salty potato chips, in this case extracellular fluid will become more hypertonic than the intracellular fluid, and so cell will shrink due to the movement of water from inside the cell toward the extracellular compartments which will expand, (EXTRACELLULSR EDEMA), okay, imagine a giant salty potato chips instead.
- Now imagine the opposite case, that you have drunk 10 liter of pure water, then extracellular fluid will become more hypotonic than the intercellular, and so, cell will expand, and extracellular compartment will shrink, (INTRACELLULAR EDEMA).

This is an example, you don't have to memorize it, just understand what is happening :)

Measuring Body Fluids

We measure the body fluid simply by using what we call "**Dilution Principle**".

For example, if you have 1 ml of a solution containing 10 mg/ml of dye is injected into a fluid compartment, but you don't know the volume of that fluid, after distribution of the dye you are estimating the concentration of it, and the final concentration is 0.01 mg/ml, the unknown volume can be calculated as follows:

Use this equation $C_A V_A = C_B V_B$, by simple rearrangement of the equation, you can calculate the unknown V_B as

$$\text{Volume B} = \frac{\text{Volume A} \times \text{Concentration A}}{\text{Concentration B}} \quad = \quad \text{Volume B} = \frac{1\text{ ml} \times 10\text{ mg/ml}}{0.01\text{ mg/ml}} = 1000\text{ ml}$$

C_A → is the initial concentration.

V_A → is the initial volume.

C_B → is the final estimated concentration.

V_B → is the final unknown volume.

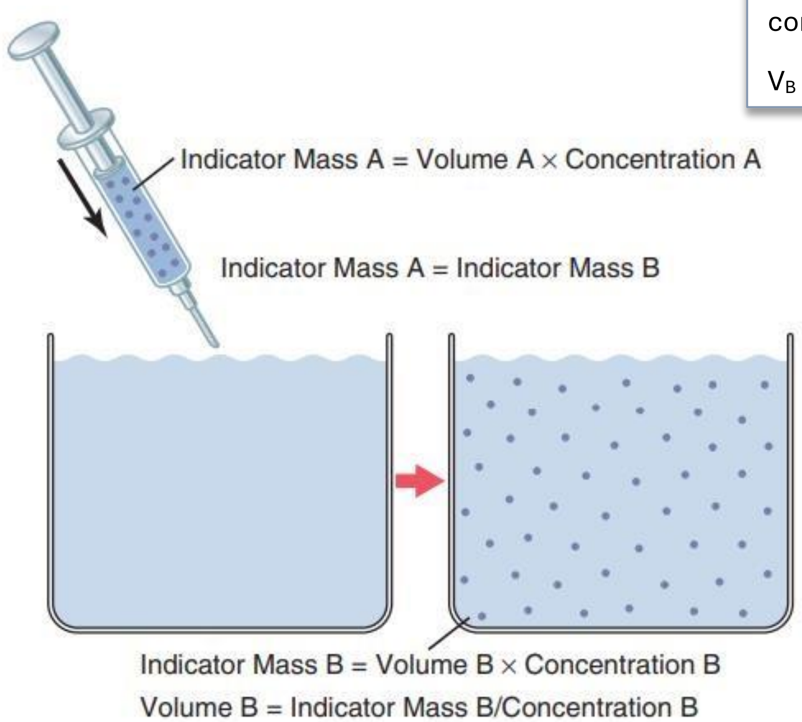


Figure 25-4. Indicator-dilution method for measuring fluid volumes.

- **Properties of tracers used for calculation of volumes:**

For the use of these dyes in a human body we have strict properties, we use substances don't have bad effects in our body. We have a lot of characteristics for these dyes that must be fullfed to use them in measurement.

Properties of an "**<u>Ideal Tracer</u>**", the tracer should:

- Be nontoxic.
- Be rapidly and evenly distribute fast throughout the nominated compartment does not enter any other compartment.

- For example, if you would like to measure only the ECM, it must be distributed only on it.

- Not be metabolized in the equilibration period.

- The distribution needs time to occur.

- Not be excreted (or excretion is able to be corrected for) during the equilibration period. (If it's you have to consider the excreted amount)
- Be easy to measure.

- You don't have any difficulty in using it.

- Not interfere with body fluid distribution.

- For example, I can't use highly amount of radioactive sodium.

1. Because its bad effect on the body.
2. The sodium may affect the distribution of fluids.

- **The measurement of total body water -volume- is simply done by using:**

1) Radioactive water (^3H_2O, T_2O, Tritium) or heavy water (^2H_2O, D_2O, Deuterium) (radioactivity → **is an indicator of concentration**)

- **This will mix with the total body water in just a few hours** and the dilution method for calculation can be used.

For example, you injected 1 ml of radioactive water (**radioactive water is like concentration**) in your body, after distribution within the body fluid you take out from your body 1 ml of plasma and measuring the radioactivity, what you will find that the radioactivity is much less than the initial one, by using dilution principle:

The C_B is the final concentration of radioactivity we are having.

The C_A is the initial radioactivity that you started with (**which could be high radioactivity**).

2) Antipyrine, which is very lipid soluble, can rapidly penetrate cell membranes and distribute itself uniformly throughout the intracellular and extracellular compartments. (**Not radioactive**)

- **Measurement of ECF volumes:**

Volume of extracellular fluid can be estimated using any of several substances that disperse in the plasma and interstitial fluid but do not readily permeate the cell membrane, they include:

- $^{22}Na^{+}$ "**Sodium Space**" (**radioactive**)
- ^{125}I-Iothalamate (**radioactive**)
- Thiosulfate
- Inulin, substance can't pass from the ECF toward the ICF "**Inulin Space**." (**Not radioactive**)

A tiny amount won't affect sodium shifting but will have a big effect on radioactivity.

When any one of these substances is injected into the blood, it usually disperses almost completely throughout the extracellular fluid within 30 to 60 minutes.

Some of these substances such as radioactive sodium, may diffuse into the cells in small amounts.

Therefore, one frequently speaks of the sodium space (**ECF are measuring with using sodium**) or the inulin space (**ECF are measuring with using inulin**), instead of calling the measurement the true extracellular fluid volume.

- **Calculation of ICF Volume:**

We use radioactive sodium (and other substances) to measure the ECF volume, so what we use to measure the ICF volume?

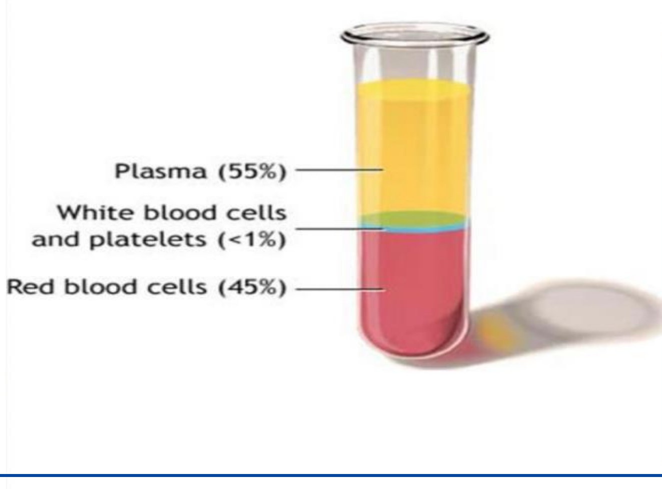
Maybe you would think of potassium, but actually the ICF volume cannot be measured directly. However, it can be calculated as:

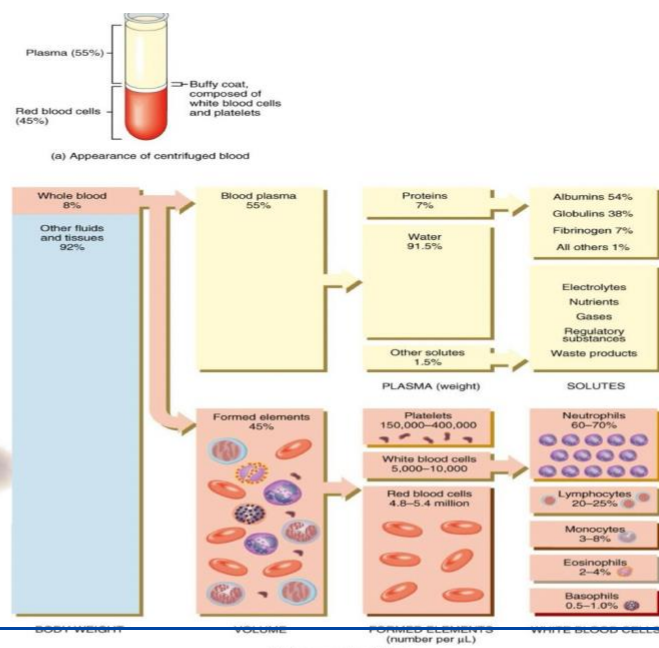
Intracellular volume = Total body water - Extracellular volume

Very important note: the doctor asked this question in his past exams, and potassium was one of the choices, so keep it in your mind we don't use potassium when we measure the ICF volume.

- We can also measure the plasma volume and the total body volume, for measuring the plasma volume we need a substance that cannot lead to the interstitial fluid (**can distributed only within the plasma**).

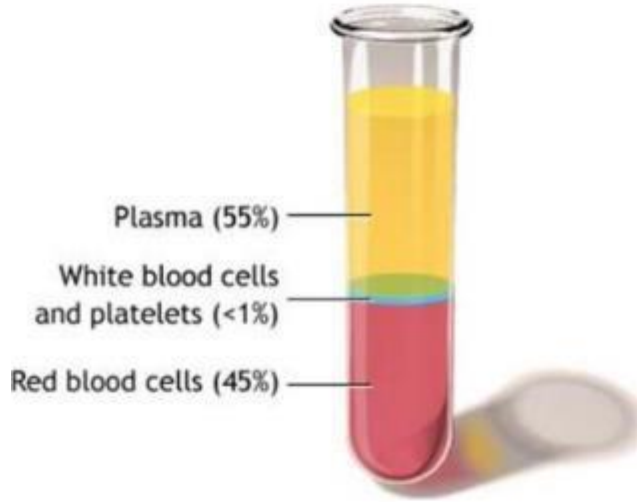
Before we know how to measure the plasma volume, we have to know what is the plasma and what it made of?





As you see, if you are taking any amount of blood, put it in a tube, centrifuging that tube, then you will get centrifugation cells.

Plasma: is the noncellular part of the blood (the fluid around it), it exchanges substances continuously with the interstitial fluid through pores of the



The fraction of the total blood volume composed of cells (**volume occupied by RBC**) is called packed cell volume (PCV) they also call it "**<u>hematocrit</u>**".

- **Normal PCV is 45% as shown.**

This is a useful test to make sure that you have a good health, we can use it to know if we have anemia or not but it's not the only indicator, we also depend on the count of RBC which is normally 5 ml/μL. For example, if someone has less amount of RBC then the PCV will decrease, and you will know that there is something unusual.

E.G:

1) If a person has a PCV of 35% and normal count → microcytic anemia.

2) If a person has a normal PCV and 3 million RBC → anemia

3) If the cell volume is bigger than normal, after calculation of Mean Corpuscular Volume (MCV) = hematocrit divided by number of RBC in 1 microliter → megaloblastic anemia

Plasma Composition:

- Water: > 90%
- Small molecule: 2%, it is electrolytes, nutriment, metabolic products, hormone, enzymes, etc.
- Protein: 60-80 g/L, plasma protein include:

a- Albumin (40-50 g/L) (54%)

b- Globulins (20-30 g/L, α_1-, α_2, β-, γ-) (38%)

c- Fibrinogen(coagulation): a protein structure which forming a clot if someone having hemorrhage to stop it (7%).

γ- → contain high levels of antibodies.

Most of albumin and globulin made from liver.

Fibrinogen before clotting is soluble but after is insoluble, if we had a coagulation, then we centrifuged the blood we won't see plasma because the clotting used this protein so the fibrinogen will be sedimented with blood cells instead we will have **Serum** which is plasma without these clotting factors, and it will be super mutant.

Important notes:

1. The importance of plasma membrane is reabsorbing fluids from the interstitial to intravascular.

2. liver problems and nephritic syndrome cause protein loss which causes edema (حالة مرضية تسبب تورمات).

- Measurement of plasma volume: -

- We can use: 1. 125I-Albumin (RISA) (Radio iodide albumin), It can't be distributed out of the vascular fluid, and it is radioactive (radioactive iodine).

2. Evans Blue (Dye (T1824)) which can be distributed only inside vessels.

-Now concerning the blood volume: we can measure it by:

1- using labeled red blood cells (We label RBCs with iodide chromium (51Cr), then we inject them in the blood), after that, we use dilution principle, the doctor said that: he hadn't placed information concerning the fluorescent tag, so it is enough to know that we can use labeled red blood cells, However, we can use fluorescent dyes rather than radioactive dyes.

2- We can use:

- If one measures plasma volume using the methods described earlier, blood volume can also be calculated if one knows the hematocrit, (using the equation shown earlier).

****Hematocrit: the fraction of the total blood volume composed of cells, for example, if plasma volume is 3 liters and hematocrit is 0.40, total blood volume would be calculated as 3 liters/(1-0.4) = 5 liters.**

$$\text{Total blood volume} = \frac{\text{Plasma volume}}{1 - \text{Hematocrit}}$$

https://www.youtube.com/watch?v=v3BTWpNTyLU

Additional Resources

رسالة من الفريق العلمي:

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