The ability of the kidney to dilute or concentrate urine

The kidney has the ability to excrete diluted or concentrated urine this is very important in maintaining ECF volume and osmolarity.

a-In case of increased water intake ,the ECF volume is increased and its osmolarity is decreased and this leads to inhibition of ADH secretion ,leading to decreased water Reabsorption by collecting tubules leading to formation of large volume of dilute urine so the ECF volume and osmolarity is corrected.

b-While in cases of decreased water intake ECF osmolarity is increased with a decrease in body water content.

The body has to conserve water by decreasing water output by excreting a small volume of highly concentrated urine.

This mechanism is more complicated than excretion of diluted urine as discussed below.

<u>The Significance of the ability of the kidney to excrete concentrated urine:</u>

Normal osmolarity of body fluids is about 300 mOsm / L

In order to excrete 600 mOsm of metabolic waste products produced daily under normal conditions you need 2 litters of water to excrete an iso-osmotic solution that cause no harm to the kidney.

In case of restricted water intake (as in desert) the loss of this 2 litters of water will be harmful to the body water content, however the kidney has the ability to excrete concentrated urine as high osmolarity as 1200 mOsm / L

The mechanism:

In order to excrete concentrated urine ,the kidney has to increase water Reabsorption by the collecting tubules .

This process needs 2 factors.

1-The action of ADH to open water intracellular channels.

2-High and stable osmotic gradient in the area surrounding the collecting tubules to maintain high rate of water movement according to osmotic gradient through opened channels.This can be done only by a special mechanism in the renal medulla called Counter current mechanism.

Steps needed for creation of osmotic gradient.

1-Increaded solute load in the renal medulla by:

a-Active Na+ Reabsorption in the thick ascending limb of loop of Henle followed by passive movement of other solutes e.g CL- and HCO3 .

b-Active Na+ Reabsorption by the collecting tubules.

c-Passive urea Reabsorption by the collecting tubules.(solvent drag*****)

2-Creation of Osmotic gradient by Counter current system.

Definition of counter current system:

It is a system characterized by the presence of:

- U shaped tube with its 2 limbs close to each other.
- Continuous counter current stream.
- A source of energy.

All these characters are found in the loop of Henle as:

- It consists of U shaped tube with 2 limbs are close to each other.
- The tubular fluid flows in the 2 limbs in a counter current stream.

- The source of energy is the active Na+ - K + pump of the thick ascending limb of loop of Henle.

The loop of Henle acts as a **counter current multiplier** which multiply the tonicity of the medullary interstitium about 5 times (from 300m.osm/L at the outer medulla to 1400m.osm/L at the renal papilla).

To understand how the counter current can create an osmotic gradient we have to imagine that this process can occur in successive steps beginning from position Zero as follow:

Position Zero:

We imaging that fluid entering and leaving loop of Henle is Iso-Osmotic with fluid flowing out of proximal tubule = 300 mOsm / L.

Steps:

<u>Ascending limb:</u> is impermeable to water but permeable to solutes, thus its main function is removal of solutes.

Na Cl is transferred to medullary interstitium (M.I) passively in thin part and actively in the thick part.

As the ascending limb is impermeable to water, so tubular fluid inside he ascending limb is hypotonic to M.I (it's 200 m osm/ L less than M.I at any transverse level) so fluid leaving the ascending limb is hypotonic (100 m osm/L). This results in:

1- Hypertonic medullary interstitum in a longitudinal direction from 300 (outer medulla) – 1400 m osm/ L (inner medulla). The tonicity is multiplied about 5 times.
2- Hypotonic fluid leaves medulla: at any transverse level, the osmolarity is 200 m osm/L less than M.I.

Descending limb: is impermeable to Na Cl but permeable to water thus its main function is water removal.

The hypertonic M.I produced by the ascending limb will absorb water from descending limb till the fluid in the descending limb becomes isotonic with M.I at any transverse level. The end of descending limb at renal papilla is 1400 m osm/L.

Preservation of osmotic gradient (the role of vasa recta as a counter current exchanger):

The preservation of osmotic gradient is very important because any osmotic gradient in the medullary tissue could be washed out by the medullary blood flow.

However the blood supply to the medulla (vasa recta) has some characters that help to maintain the solute load and prevent the washout of the osmotic gradient in the medullary tissue.

Vasa recta is a loop of peritubular capillaries, which run close to and parallel to the loop of Henle. It is characterized by.

a-U shaped loop of capillaries.

b-Counter current blood flow.

c-High permeability to water and electrolytes.

d- Low blood flow (0.25 ml / gm tissue / min)

The role of vasa recta in the counter current mechanism is to exchange the Nacl and urea between its 2 limbs so as to keep them in the medullary interstitial fluid as follow:

1-In descending limb of vasa recta water flow out and Nacl flows inside due to increased osmolarity of medullary ISF as blood moves deep in the medulla.

2-In ascending limb ,and as osmolarity decreases gradually toward the cortex H2O moves again to inside the ascending limb ,while Nacl and urea moves out in the medullary interstatium.

The net result of the above 2 points osmolarity is kept constant in the medullary interstatium.

The function of vasa recta as a counter current exchanger is to maintain renal medullary hyperosmolority through:

1-Trapping of solutes (Nacl and urea) in renal medulla.

2-removing excess water from medullary interstitium

By:

Walls of vasa recta are highly permeable so allowing passive diffusion of water and solutes

In their descending limbs:

The solutes diffuse (Nacl and urea) from medullary interstatium into the vessel because its concentration is higher than blood so diffuses according to concentration gradient into vasa recta.

At the same time water diffuses out into medullary interstitiatium because.Osmolority of Medullary interstatium exceeds that of blood .

Net result:

Blood become gradually concentrated as it moves downward until an osmotic pressure of 1200 mOsm at the tip.

In ascending limb:

Solutes diffuses from blood into the medullary interstatium as osmolarity in the interstatium gradually decrease.

H2O moves from interstatium to the blood again.

Nacl and urea moves out of the ascending limb to the Medullary interstatium.

Net result:

The blood flows out of the medulla carries no solutes but only a small amount of excess water, which is absorbed by the renal tubules in the medulla, thus Osmolority is kept constant in medullary interstatium.

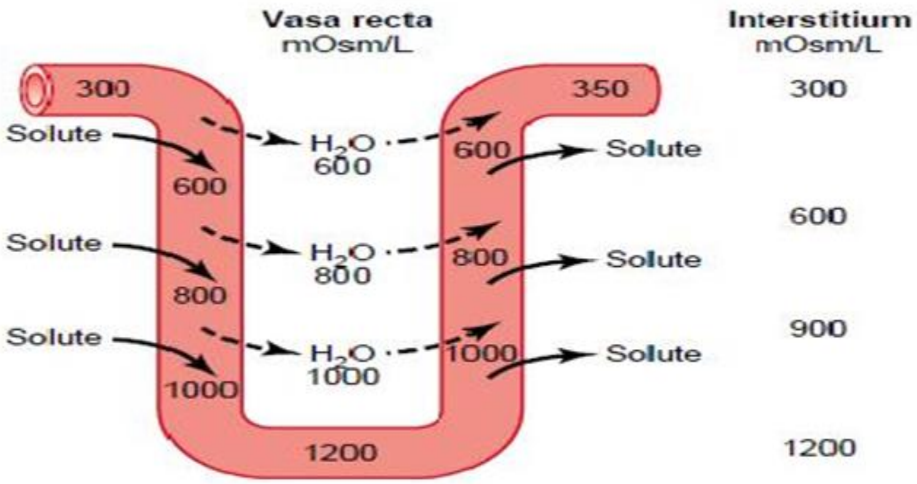

Figure (22): vasa recta as a counter current exchanger.

Role of urea in urine concentration:

Urea plays an important role in the concentrating ability of the kidney. It shares in 45-50% of osmolarity of M.I.

This can be explained by the following steps:

Step (1)

Concentration of urea in the tubular fluid increases gradually as most renal tubules are impermeable to urea (ascending limb of L.H, DCT, cortical CD and outer medullaryCD),while water and other solutes are absorbed in large amounts along renal tubules.

Step (2)

Concentration of urea reach its maximum level in the late collecting duct (inner medullary collecting duct)which is highly permeable to urea in the presence of (ADH), so urea is passively reabsorped according to concentration gradient.

Step (3)

Absorption of urea in this segment adds much to the osmolarity of lower medulla, which in turn increases the rate of H2O Reabsorption by descending limb of loop of Henle so increasing NacL concentration in the tubular fluid that reach ascending limb. Urea diffuses from M.I. to the thin ascending limb and to the descending limb of L.H till reaches inner medullary collecting duct to be reabsorbed again by ADH which is known as **urea trapping** or **urea cycling**.

Step (4)

When NaCL rich fluid reach the ascending limb which is permeable to NaCL, passive NaCL Reabsorption occurs increasing the solute load in the renal medulla.

Role of ADH in formation of concentrated urine:

ADH plays a key role in urine concentration by:

1- Increase CD permeability to water along osmotic gradient of M.I.
2- Increase urea reabsorbtion passively from inner medullary CD.
3- V.C of the efferent arteriole which lead to:
    a- increase osmolarity of M.I. by decrease washing out of solutes from it.

b- Increase the filtered load of Na+ leading to increase Na+ reaching to ascending limb of L.H. and more removal of Na+ from ascending limb to M.I adding to the hypertyonicity of M.I.