CONCENTRATION OF URINE

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INTRODUCTION

- Every day 180 L of glomerular filtrate is formed with large quantity of water.
- If this much of water is excreted in urine, body will face serious threats.
- So the concentration of urine is very essential.
- Osmolarity of glomerular filtrate is same as that of plasma and it is 300 mOsm/L.
- But, normally urine is concentrated and its osmolarity is four times more than that of plasma, i.e. 1,200 mOsm/L.

- Osmolarity of urine depends upon two factors:

1. **WATER CONTENT IN THE BODY**
2. **ANTIDIURETIC HORMONE (ADH)**

- Mechanism of urine formation is the same for dilute urine and concentrated urine till the fluid reaches the distal convoluted tubule.
- However, dilution or concentration of urine depends upon water content of the body.

FORMATION OF DILUTE URINE

- When, water content in the body increases, kidney excretes dilute urine.
- This is achieved by inhibition of ADH secretion from posterior pituitary.
- So water reabsorption from renal tubules does not take place leading to excretion of large amount of water upto 20 lit./day.
- This makes the urine dilute.

FORMATION OF CONCENTRATED URINE

- When the water content in body decreases, kidney retains water and excretes concentrated urine.
- Formation of concentrated urine is not as simple as that of dilute urine.
- It involves two processes:

1. Development and maintenance of medullary gradient by countercurrent system
2. Secretion of ADH

DEVELOPMENT AND MAINTENANCE OF MEDULLARY GRADIENT

- Cortical interstitial fluid is isotonic to plasma with the osmolarity of 300 mOsm/L.
- Osmolarity of medullary interstitial fluid near the cortex is also 300 mOsm/L.

- However, while proceeding from outer part towards the inner part of medulla, the osmolarity increases gradually and reaches the maximum at the inner most part of medulla near renal sinus.
- Here, the interstitial fluid is hypertonic with osmolarity of 1,200 mOsm/L.
- This type of gradual increase in the osmolarity of the medullary interstitial fluid is called the medullary gradient.
- It plays an important role in the concentration of urine.

COUNTERCURRENT MECHANISM

- Kidney has some unique mechanism called countercurrent mechanism, which is responsible for the development and maintenance of medullary gradient and hyperosmolarity of interstitial fluid in the inner medulla.

- A countercurrent system is a system of 'U'shaped tubules (tubes) in which, the flow of fluid is in opposite direction in two limbs of the 'U'shaped tubules.

DIVISIONS OF COUNTERCURRENT SYSTEM

- Countercurrent system has two divisions:

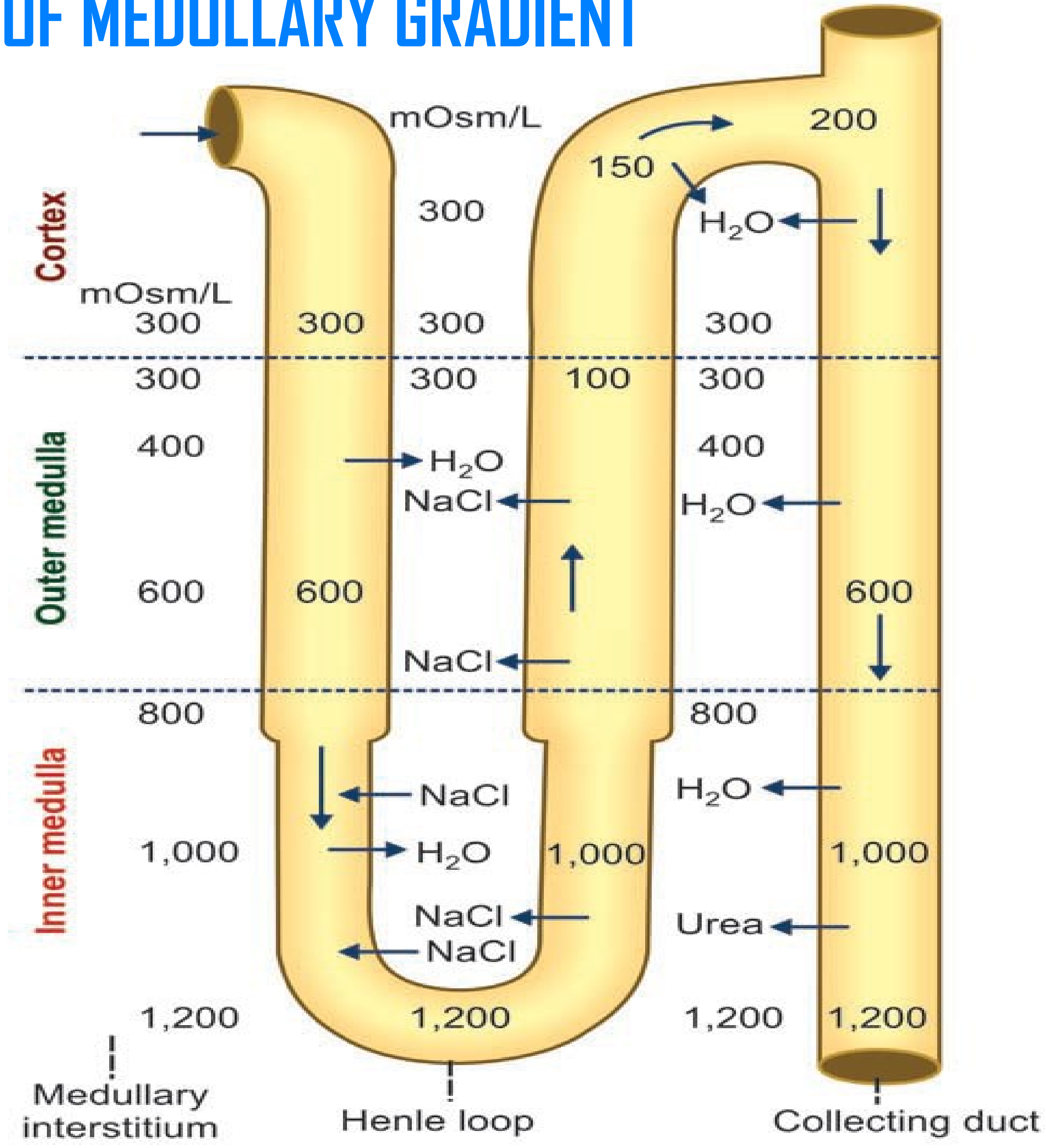
1. **COUNTERCURRENT MULTIPLIER FORMED BY LOOP OF HENLE**
2. **COUNTERCURRENT EXCHANGER FORMED BY VASA RECTA**

3. COUNTERCURRENT MULTIPLIER

- Loop of Henle functions as countercurrent multiplier.
- It is responsible for development of hyperosmolarity of medullary interstitial fluid and medullary gradient.

ROLE OF LOOP OF HENLE IN DEVELOPMENT OF MEDULLARY GRADIENT

- Juxtamedullary nephrons plays a major role as countercurrent multiplier because loop of Henley in these nephrons is long and extends upto the deeper parts of medulla.
- Sodium chloride and other solutes are actively reabsorbed from ascending limb causes hyperosmolarity into the medullary interstitium.
- Now, due to the concentration gradient, the sodium and chlorine ions diffuse into the descending limb from medullary interstitium and reach the ascending limb again via hairpin bend.



- Thus, the sodium and chlorine ions are repeatedly recirculated between the descending and ascending limb of Henle loop through medullary interstitial fluid leaving a small portion to be excreted in the urine.
- Apart from this there is regular addition of more and more new sodium and chlorine ions into descending limb by constant filtration.
- Thus, the reabsorption of sodium chloride from ascending limb and addition of new sodium chlorine ions into the filtrate increase or multiply the osmolarity of medullary interstitial fluid and medullary gradient.
- Hence, it is called countercurrent multiplier.

OTHER FACTORS RESPONSIBLE FOR HYPEROSMOLARITY

RECIRCULATION OF UREA

- Fifty percent of filtered urea is reabsorbed in proximal convoluted tubule along with an equal amount of urea is secreted in the loop of Henle.

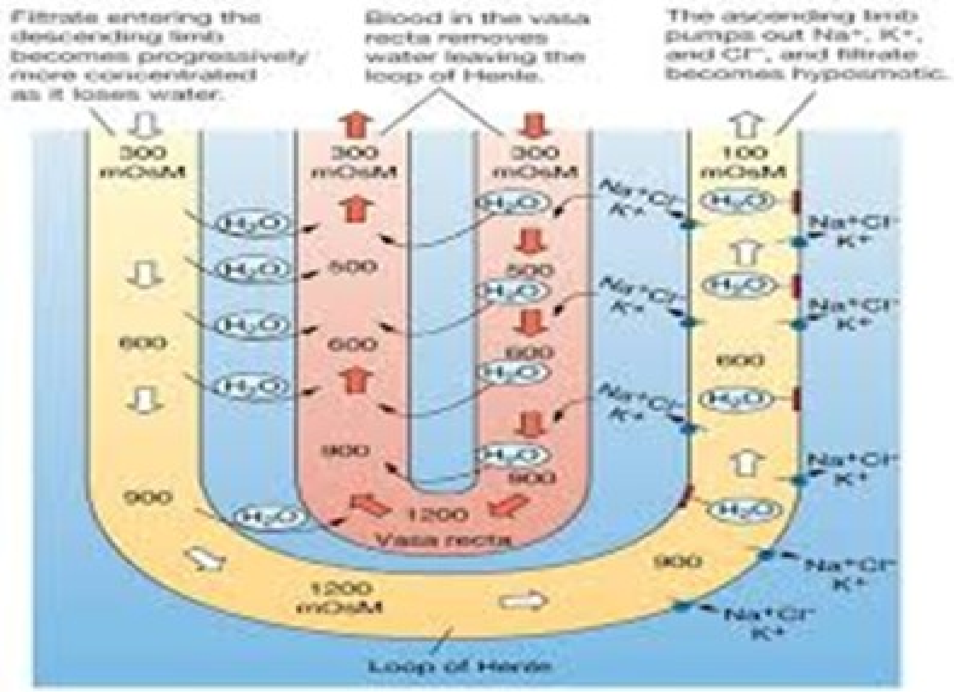
- So in distal convoluted tubule amount of urea is increased as in glomerulus filtrate.
- Normally Collecting duct is impermeable to urea. But due to water reabsorption from distal convoluted tubule and collecting duct in the presence of ADH, urea concentration increases in collecting duct.
- Now due to concentration gradient, urea diffuses from the collecting duct into medullary interstitium. By this the concentration of urea increases in the inner medulla resulting in hyperosmolarity.
- Again, by concentration gradient, urea enters the ascending limb. From here, it passes through distal convoluted tubule and reaches the collecting duct.
- Urea enters the medullary interstitium from collecting duct. By this way urea **recirculates** repeatedly and helps to maintain the hyperosmolarity of inner medullary interstitium.
- Only a small amount of urea is excreted in urine.

2. COUNTERCURRENT EXCHANGER

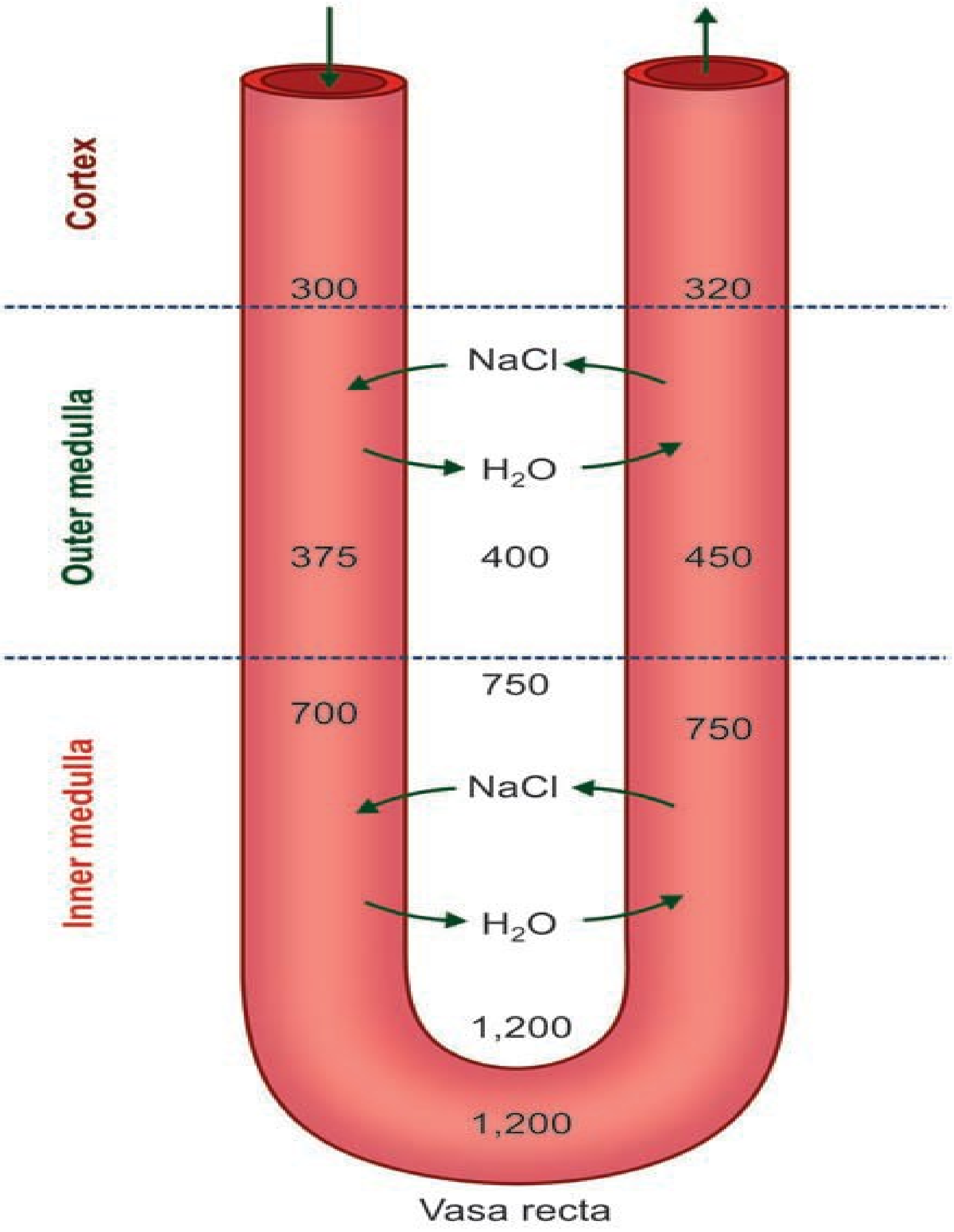
- Vasa recta functions as countercurrent exchanger.
- It is responsible for the maintenance of medullary gradient, which is developed by countercurrent multiplier.

ROLE OF VASA RECTA IN THE MAINTENANCE OF MEDULLARY GRADIENT

- Vasa recta acts like countercurrent exchanger because of its position.
- It is also ‘U’shaped tubule with a descending limb, hairpin bend and an ascending limb.
- Vasa recta runs parallel to loop of Henle but in opposite direction.

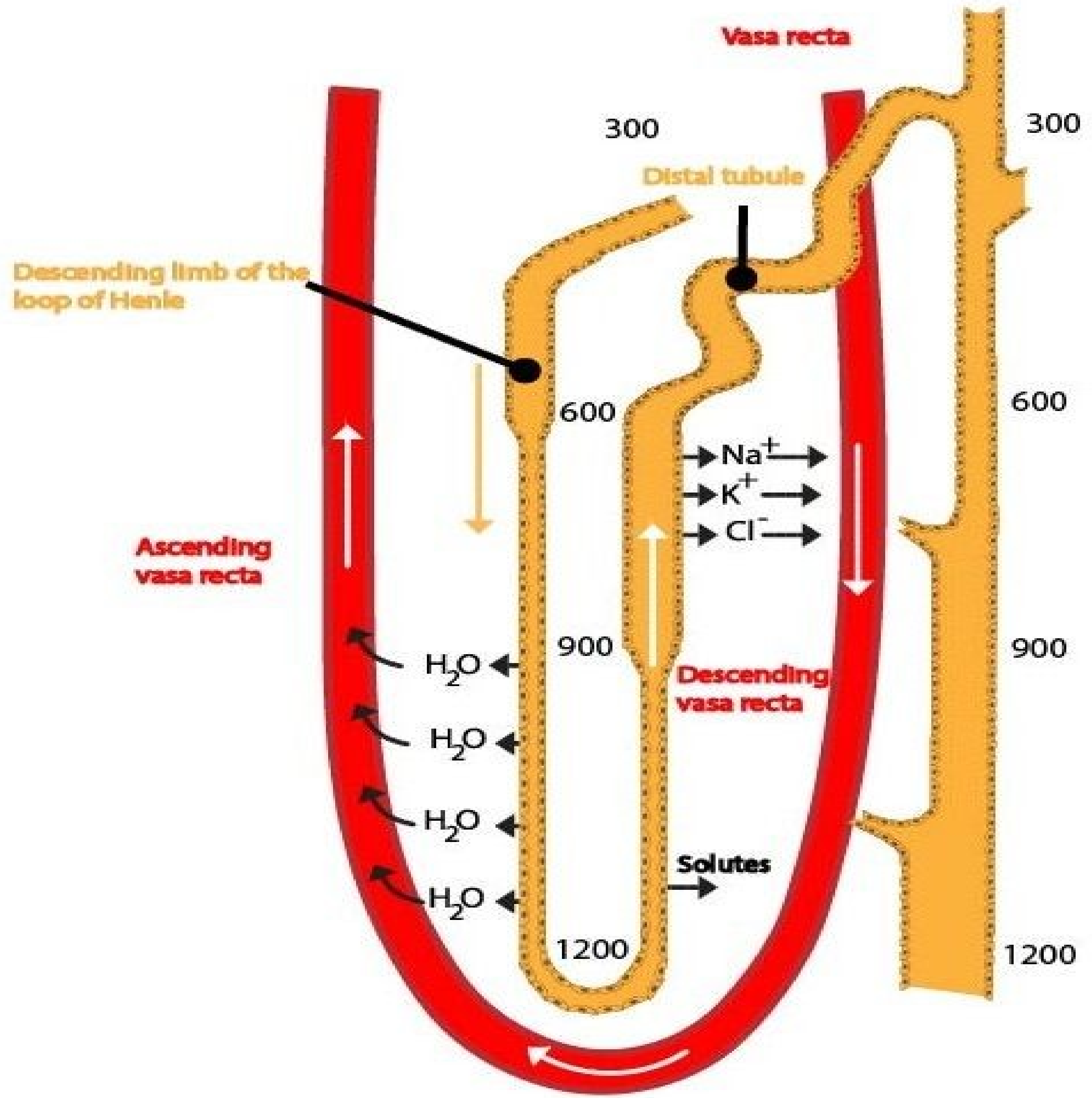


- The sodium chloride reabsorbed from ascending limb of Henle loop enters in the descending limb of vasa recta via the medullary interstitium.
- Simultaneously water diffuses from descending limb of vasa recta into medullary interstitium.
- The blood flows very slowly through vasa recta. So, a large quantity of sodium chloride accumulates in descending limb of vasa recta and flows slowly towards ascending limb.
- By the time the blood reaches the ascending limb of vasa recta, the concentration of sodium chloride increases very much. This causes diffusion of sodium chloride into the medullary interstitium.



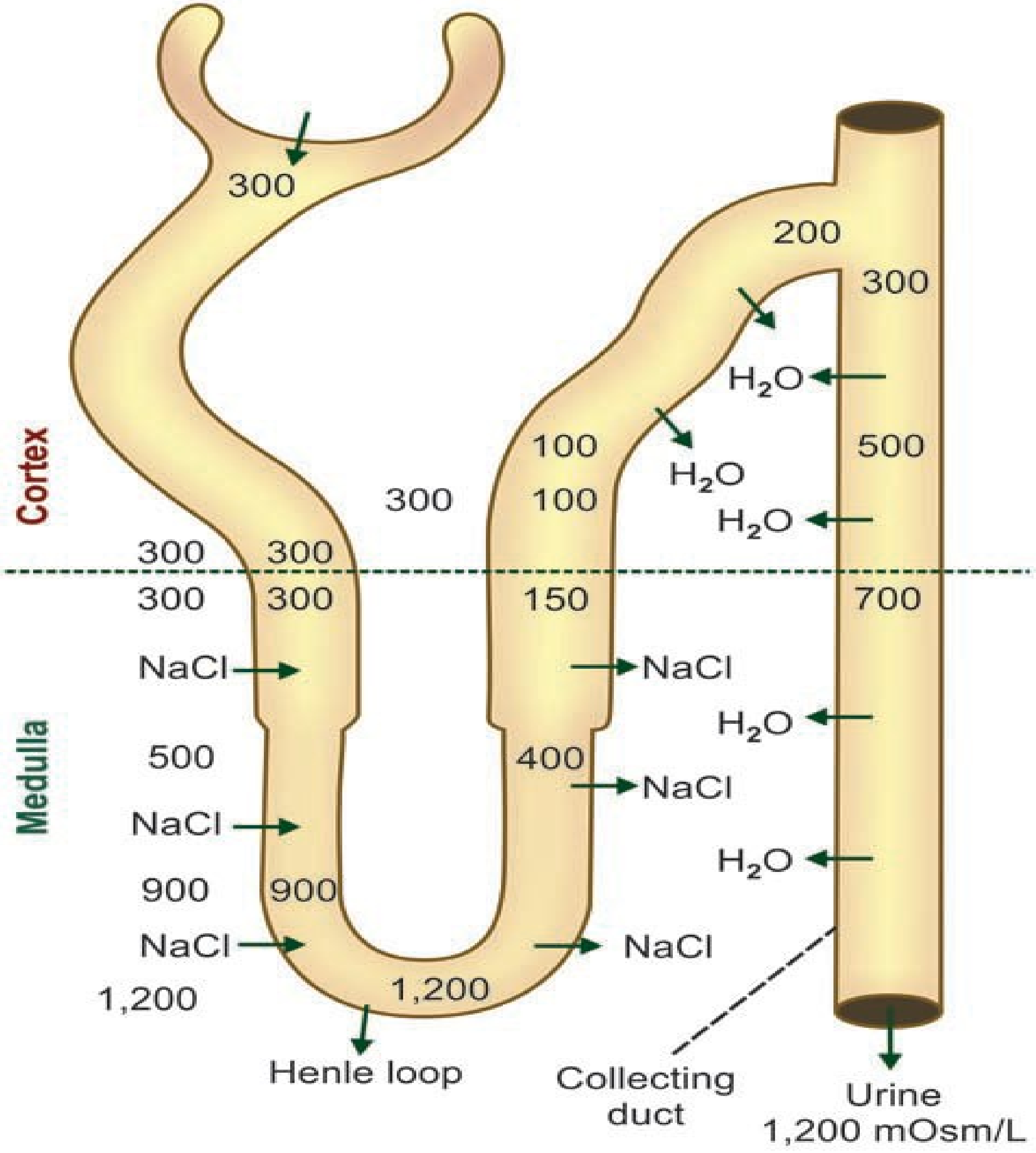
- Simultaneously, water from medullary interstitium enters the ascending limb of vasa recta. And the cycle is repeated.
- Therefore, when blood passes through the ascending limb of vasa recta, sodium chloride diffuses out of blood and enters the interstitial fluid of medulla and, water diffuses into the blood.
- Thus, vasa recta retains sodium chloride in the medullary interstitium and removes water from it. So, the hyperosmolarity of medullary interstitium is maintained.
- Recycling of urea also occurs through vasa recta.
- From medullary interstitium, along with sodium chloride, urea also enters the descending limb of vasa recta.

- When blood passes through ascending limb of vasa recta, urea diffuses back into the medullary interstitium along with sodium chloride.
- Thus, sodium chloride and urea are exchanged for water between the ascending and descending limbs of vasa recta, hence this system is called countercurrent exchanger.



ROLE OF ADH

- Final concentration of urine is achieved by the action of ADH.
- Normally, the distal convoluted tubule and collecting duct are not permeable to water.
- But the presence of ADH makes them permeable, resulting in water reabsorption.
- Water reabsorption induced by ADH is called **facultative reabsorption of water**.
- A large quantity of water is removed from the fluid while passing through distal convoluted tubule and collecting duct. So, the urine becomes hypertonic with an osmolarity of 1,200 mOsm/L.

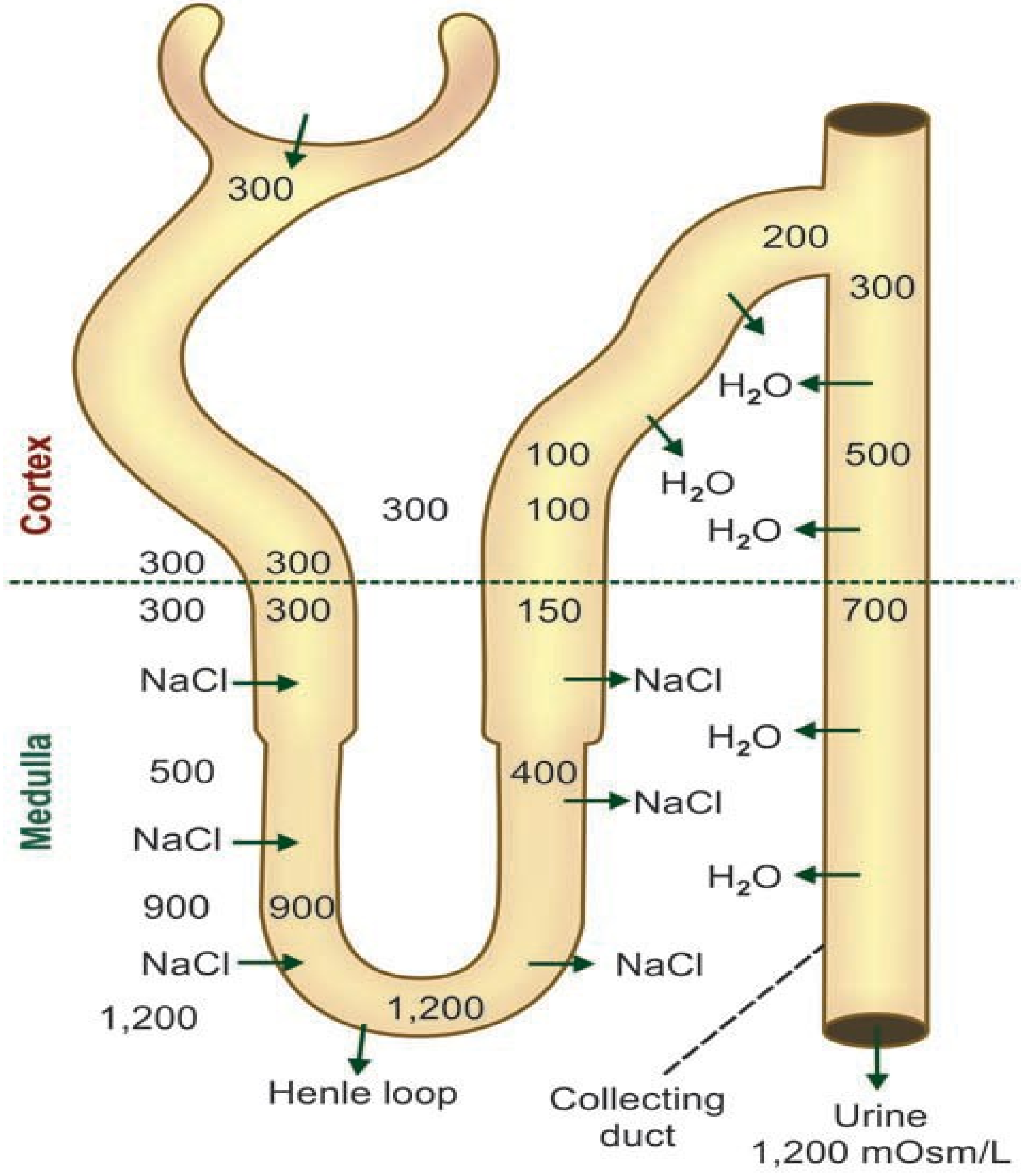


SUMMARY OF URINE CONCENTRATION

- When the glomerular filtrate passes through renal tubule, its osmolarity is altered in different segments as described below.

1. BOWMAN CAPSULE

- Glomerular filtrate collected at the Bowman capsule is **isotonic to plasma**.
- This is because it contains all the substances of plasma except proteins.
- Osmolarity of the filtrate at Bowman capsule is 300 mOsm/L.



2. PROXIMAL CONVOLUTED TUBULE

- When the filtrate flows through proximal convoluted tubule, there is active reabsorption of sodium and chloride followed by **obligatory reabsorption of water.**
- So, the osmolarity of fluid remains the same as in the case of Bowman capsule, i.e. 300 mOsm/L. Thus, in proximal convoluted tubules, the fluid is **isotonic to plasma.**

3. THICK DESCENDING SEGMENT

- When the fluid passes from proximal convoluted tubule into the thick descending segment, water is reabsorbed from tubule into outer medullary interstitium by means of osmosis.
- It is due to the increased osmolarity in the medullary interstitium, i.e. outside the thick descending tubule. The osmolarity of the fluid inside this segment is between 450 and 600 mOsm/L. That means the fluid is slightly **hypertonic to plasma.**

4. THIN DESCENDING SEGMENT OF HENLE LOOP

- As the thin descending segment of Henle loop passes through the inner medullary interstitium (which is increasingly hypertonic) more water is reabsorbed.
- This segment is highly permeable to water and so the osmolarity of tubular fluid becomes equal to that of the surrounding medullary interstitium.
- In the short loops of cortical nephrons, the osmolarity of fluid at the hairpin bend becomes 600 mOsm/L, where in the long loops of juxtamedullary nephrons osmolarity is 1,200 mOsm/L at the same place. Thus in this segment the fluid is **hypertonic to plasma.**

5. THIN ASCENDING SEGMENT OF HENLE LOOP

- When the thin ascending segment of the loop ascends upwards through the medullary region, osmolarity decreases gradually.
- Due to concentration gradient, sodium chloride diffuses out of tubular fluid and osmolarity decreases to 400 mOsm/L. The fluid in this segment is slightly **hypertonic to plasma.**

6. THICK ASCENDING SEGMENT

- This segment is impermeable to water. But there is active reabsorption of sodium and chloride from this.
- Reabsorption of sodium decreases the osmolarity of tubular fluid to a greater extent.
- The osmolarity is between 150 and 200 mOsm/L. The fluid inside becomes **hypotonic to plasma.**

7. DISTAL CONVOLUTED TUBULE AND COLLECTING DUCT

- In the presence of ADH, distal convoluted tubule and collecting duct become permeable to water resulting in water reabsorption and final concentration of urine.
- It is found that in the collecting duct, Principal (P) cells are responsible for ADH induced water reabsorption.
- Reabsorption of large quantity of water increases the osmolarity to 1,200 mOsm/L. The urine becomes **hypertonic to plasma.**

THANK YOU