Reabsorption of Salt and Water

After studying this lecture, you should be able to . . .

1. Define the obligatory water loss.

2. Describe the mechanism of Na\(^{++}\) reabsorption in the distal tubule and explain why this reabsorption occurs together with the secretion of K\(^{+}\).

3. Explain the role of aldosterone hormone in Na/K balance.

4. Show the physiological effects of fluid overload in the body.
Most of the salt and water filtered from the blood is returned to the blood through the wall of the proximal tubule. The reabsorption of water occurs by osmosis, in which water follows the transport of NaCl from the tubule into the surrounding capillaries. Most of the water remaining in the filtrate is reabsorbed across the wall of the collecting duct in the renal medulla. This occurs as a result of the high osmotic pressure of the surrounding tissue fluid, which is produced by transport processes in the loop of Henle. Although about 180 L of glomerular ultrafiltrate are produced each day, the kidneys normally excrete only 1 to 2 L of urine in a 24-hour period. Approximately 99% of the filtrate must thus be returned to the vascular system, while 1% is excreted in the urine. The urine volume, however, varies according to the needs of the body. When a well-hydrated person drinks a liter or more of water, urine production increases to 16 ml per minute (the equivalent of 23 L per day if this were to continue for 24 hours). In severe dehydration, when the body needs to conserve water, only 0.3 ml of urine per minute, or 400 ml per day, are produced.

A volume of 400 ml of urine per day is the minimum needed to excrete the metabolic wastes produced by the body; this is called the **obligatory water loss**. When water in excess of this amount is excreted, the urine becomes increasingly diluted as its volume is increased.

Regardless of the body’s state of hydration, it is clear that most of the filtered water must be returned to the vascular system to maintain blood volume and pressure. The return of filtered molecules from the tubules to the blood is called **reabsorption**. It is important to realize that the transport of water always occurs passively by osmosis; there is no such thing as active transport of water. A concentration gradient must thus be created between tubular fluid and blood that favors the osmotic return of water to the vascular system.

**Tubular Reabsorption Includes Passive and Active Mechanisms**

For a substance to be reabsorbed, it must first be transported (1) across the tubular epithelial membranes into the renal interstitial fluid and then (2) through the peritubular capillary membrane back into the blood.
Active and Passive Transport

The epithelial cells that compose the wall of the proximal tubule are joined together by tight junctions only on their apical sides that is, the sides of each cell that are closest to the lumen of the tubule. Each cell therefore has four exposed surfaces: the apical side facing the lumen, which contains microvilli; the basal side facing the peritubular capillaries; and the lateral sides facing the narrow clefts between adjacent epithelial cells.

The concentration of Na+ in the glomerular ultrafiltrate—and thus in the fluid entering the proximal tubule—is the same as that in plasma. The epithelial cells of the tubule, however, have a much lower Na+ concentration. This lower Na+ concentration is partially due to the low permeability of the plasma membrane to Na+ and partially due to the active transport of Na+ out of the cell by Na+/K+ pumps.

In the cells of the proximal tubule, the Na+/K+ pumps are located in the basal and lateral sides of the plasma membrane but not in the apical membrane. As a result of the action of these active transport pumps, a concentration gradient is created that favors the diffusion of Na+ from the tubular fluid across the apical plasma membranes and into the epithelial cells of the proximal tubule. The Na+ is then extruded into the surrounding tissue fluid by the Na+/K+ pumps.

The transport of Na+ from the tubular fluid to the interstitial (tissue) fluid surrounding the proximal tubule creates a potential difference across the wall of the tubule, with the lumen as the negative pole. This electrical gradient...
favors the passive transport of Cl− toward the higher Na+ concentration in the interstitial fluid. Chloride ions, therefore, passively follow sodium ions out of the filtrate into the interstitial fluid. As a result of the accumulation of NaCl, the osmolality and osmotic pressure of the interstitial fluids surrounding the epithelial cells are increased above those of the tubular fluid. This is particularly true of the interstitial fluid between the lateral membranes of adjacent epithelial cells, where the narrow spaces permit the accumulated NaCl to achieve a higher concentration.

An osmotic gradient is thus created between the tubular fluid and the interstitial fluid surrounding the proximal tubule. Since the cells of the proximal tubule are permeable to water, water moves by osmosis from the tubular fluid into the epithelial cells and then across the basal and lateral sides of the epithelial cells into the interstitial fluid. The salt and water that were reabsorbed from the tubular fluid can then move passively into the surrounding peritubular capillaries, and in this way be returned to the blood.

**Significance of Proximal Tubule Reabsorption**

Approximately 65% of the salt and water in the original glomerular ultrafiltrate is reabsorbed across the proximal tubule and returned to the vascular system.

The volume of tubular fluid remaining is reduced accordingly, but this fluid is still isosmotic with the blood, which has a concentration of 300 mOsm. This is because the plasma membranes in the proximal tubule are freely permeable to water, so that water and salt are removed in proportionate amounts. An additional smaller amount of salt (about 20%) is returned to the vascular system by reabsorption through the descending limb of the loop of Henle. This reabsorption, like that in the proximal tubule, occurs constantly, regardless of the person’s state of hydration. Unlike reabsorption in later regions of the
nephron (distal tubule and collecting duct), it is not subject to hormonal regulation. Therefore, approximately 85% of the filtered salt and water is reabsorbed in a constant fashion in the early regions of the nephron (proximal tubule and loop of Henle). This reabsorption is very costly in terms of energy expenditures, accounting for as much as 6% of the calories consumed by the body at rest.

Since 85% of the original glomerular ultrafiltrate is reabsorbed in the early regions of the nephron, only 15% of the initial filtrate remains to enter the distal convoluted tubule and collecting duct. This is still a large volume of fluid—15% × GFR (180 L per day) = 27 L per day—that must be reabsorbed to varying degrees in accordance with the body’s state of hydration. This “fine tuning” of the percentage of reabsorption and urine volume is accomplished by the action of hormones on the later regions of the nephron.

**Pinocytosis—an Active Transport Mechanism for Reabsorption of Proteins:**

Some parts of the tubule, especially the proximal tubule, reabsorb large molecules such as proteins by **pinocytosis**. In this process, the protein attaches to the brush border of the luminal membrane, and this portion of the membrane then invaginates to the interior of the cell until it is completely pinched off and a vesicle is formed containing the protein.

**Review of active transport**

![Diagram of active transport](image-url)
Review of secondary active transport

Renal Control of Electrolyte:

The kidneys help to regulate the concentrations of plasma electrolytes: sodium, potassium, chloride, bicarbonate, and phosphate by matching the urinary excretion of these compounds to the amounts ingested. The control of plasma Na is important in the regulation of blood volume and pressure; the control of plasma K is required to maintain proper function of cardiac and skeletal muscles.

Role of Aldosterone in Na/K Balance

Approximately 90% of the filtered Na and K are reabsorbed in the early part of the nephron before the filtrate reaches the distal tubule. This reabsorption occurs at a constant rate and is not subject to hormonal regulation. The final concentration of Na and K in the urine is varied
according to the needs of the body by processes that occur in the late distal tubule and in the cortical region of the collecting duct.

Renal reabsorption of Na and secretion of K are regulated by **aldosterone**, secreted by the adrenal cortex.

**Sodium Reabsorption**

Although 90% of the filtered sodium is reabsorbed in the early region of the nephron, the amount left in the filtrate delivered to the distal convoluted tubule is still quite large. 8% of the amount filtered is also reabsorbed through the wall of the tubule into the peritubular blood distally without the need of aldosterone. The amount of sodium excreted without aldosterone is thus 2% of the amount filtered. Although this percentage seems small, the actual amount it represents is an impressive 30 g of sodium excreted in the urine each day. When aldosterone is secreted in maximal amounts, by contrast, all of the sodium delivered to the distal tubule is reabsorbed. In this case urine contains no Na at all.

Aldosterone stimulates Na reabsorption to some degree in the late distal convoluted tubule, but the primary site of aldosterone action is in the **cortical collecting duct**. This is the initial portion of the collecting duct, located in the renal cortex, which has different permeability properties than the terminal portion of the collecting duct, located in the renal medulla.

**Potassium Secretion**

About 90% of the filtered potassium is reabsorbed in the early regions of the nephron (mainly from the proximal tubule). The remaining K will be also reabsorbed in the distal tubules. In order for potassium to appear in the urine, it must be secreted into later regions of the nephron tubule. Secretion of potassium occurs in the parts of the nephron that are sensitive to aldosterone that is, in the late distal tubule and cortical collecting duct.

As Na is reabsorbed in these regions of the nephron, the lumen of the tubule becomes more negatively charged (−50 mV) compared to the
basolateral side. This potential difference then drives the secretion of K into the tubule.

The amount of K secretion into the late distal tubule and cortical collecting duct depends on:

1. The amount of Na delivered to these regions of the nephron.
2. The amount of aldosterone secreted.

If the blood concentration of K rises, this will stimulate increased aldosterone secretion from the adrenal cortex. The aldosterone then stimulates increased reabsorption of Na and, as a result, increased secretion of K.

**Control of Aldosterone Secretion**

Since aldosterone promotes Na retention and K loss, one might predict (on the basis of negative feedback) that aldosterone secretion would be increased when there was a low Na or a high K concentration in the blood. This indeed is the case. A rise in blood K **directly** stimulates the secretion of aldosterone from the adrenal cortex. A decrease in plasma Na concentration, if it causes a fall in blood volume, also promotes aldosterone secretion. However, the stimulatory effect of a fall in blood volume on aldosterone secretion is **indirect.**
**Atrial Natriuretic Peptide (ANP)**

Expansion of the blood volume causes increased salt and water excretion in the urine. This is partly due to an inhibition of aldosterone secretion. However, it is also caused by increased secretion of a natriuretic hormone, a hormone that stimulates salt excretion, an action opposite to that of aldosterone. Atrial natriuretic peptide is produced by the atria of the heart and secreted in response to the stretching of the atrial walls by increased blood volume. In response to ANP action, the kidneys lower the blood volume by excreting more of the salt and water filtered out of the blood by the glomeruli. Atrial natriuretic peptide thus functions as an endogenous diuretic.

**Relationship between Na, K, and H**

The plasma K concentration indirectly affects the plasma H concentration (pH). Changes in plasma pH likewise affect the K concentration of the blood.

When the extracellular H concentration increases, some of the H moves into the cells and causes cellular K to diffuse outward into the extracellular fluid. The plasma concentration of H is thus decreased while the K increases, helping to reestablish the proper ratio of these ions in the extracellular fluid. A similar effect occurs in the cells of the distal region of the nephron. In the cells of the late distal tubule and cortical collecting duct, positively charged ions (K and H) are secreted in response to the negative polarity produced by reabsorption of Na.

So in case of acidosis (increase in plasma pH i.e. concentration of H) there will be plasma hyperkalemia and K will thus appear in urine.