Anatomy of the Collecting Duct System and Water Reabsorption

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This article reviews the microscopic anatomical part of the kidney known as the collecting duct system. The collecting duct system consists of a series of tubules and ducts that connect the nephrons to a minor calyx or to the renal pelvis. This collecting duct system, as the name implies, is responsible for reabsorption and excretion of different electrolytes as well as fluid balance in our bodies.

Overview

The functions of the collecting duct system are **regulated by the activity of aldosterone and vasopressin.** Aldosterone is released from the adrenal glands, whereas vasopressin (also known as antidiuretic hormone (ADH)) is released from the posterior pituitary. Vasopressin is synthesized in the hypothalamus. An absence of ADH results in a high concentration of aquaporin 2 in the storage vesicles present in the cytoplasm of collecting duct epithelial cells. Aquaporins are proteins produced within the membranes of vesicles that bud from the Golgi apparatus. They permit diffusion of water via the plasma membrane.

The main components of the collecting duct system are:

- Connecting tubules
- Cortical collecting ducts
- Medullary collecting ducts

There are 2 functional types of cells within the collecting duct system: principal cells and intercalated cells.

Microscopic Structure of the Collecting Duct System

The terminal portion of the distal convoluted tubule empties through collecting tubules, which join into a straight collecting duct in the medullary ray. Collecting ducts are different from other renal tubules because of prominent lateral borders of epithelial cells in their structure. The collecting duct system consists of different segments that have their own characteristics and functions.

Connecting Tubules

The connecting tubules are the most proximal part of the collecting duct system. They are adjacent to the distal convoluted tubule. The connecting tubules from different adjacent nephrons merge together to form what is known as **cortical collecting tubules**. The cortical collecting tubules merge together to form cortical collecting ducts.

From an embryogenic point of view, the connecting tubules are the only part of the collecting duct system that derives from the metanephric blastema. The rest of the collecting duct system derives from the ureteric bud. Because of this embryogenic difference, there is currently a debate about whether the connecting tubules are part of the nephron or the collecting duct system.

The cortical collecting ducts receive filtrate from multiple initial collecting tubules. They descend into the renal medulla to form what is known as medullary collecting ducts.

The main function of connecting tubules is the **regulation of water and electrolytes, including sodium and water.** Connecting tubules are sensitive to vasopressin; however, the cortical collecting ducts are more sensitive in comparison.

Medullary Collecting Ducts

These ducts can be **divided into outer and inner segments.** The inner segments reach more deeply into the renal medulla. Absorption of water, sodium, potassium, hydrogen, and bicarbonate continues here. This is tightly regulated by the action of the different regulatory hormones, such as vasopressin and aldosterone, as well as the fluid-balance status of the person. The presence of vasopressin enables the collecting ducts to become more permeable to water. The high osmotic pressure in the medulla is generated by the countercurrent multiplier system in the loop of Henle, which draws out water from the renal tubules, back to vasa recta.

Papillary collecting ducts

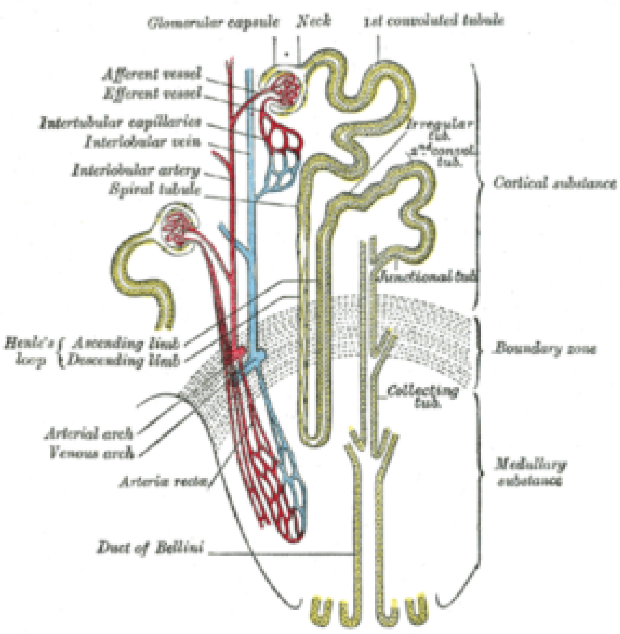

Image: Scheme of renal tubule and its vascular supply. By Henry Gray, License: Public Domain

These structures were previously known as ducts of Bellini. They represent the most distal portion of the collecting duct system. They **receive renal filtrate** from the medullary collecting ducts and empty into a minor calyx. Papillary ducts also contribute to water reabsorption and electrolyte balance.

The cells that comprise the upper portion of papillary collecting ducts are similar to the cells found in the rest of the collecting system. They can be divided into principal and intercalated cells. The cells of the lower papillary ducts near the papillary duct junction with the minor calyx derive from urothelium.

Absorption of water, sodium, and urea and excretion of hydrogen and potassium are again regulated by aldosterone and vasopressin.

Cells of Collecting Duct System

All segments of the collecting duct system have intercalated cells except for the distal portion of the papillary collecting ducts. In addition to the intercalated cells, each segment of the collecting duct system has segment-specific cells. The different types of cells found in each segment of the collecting duct system, in addition to the intercalated cells, are shown below:

Connecting tubule cells	Connecting tubules
Principal cells	• Cortical collecting ducts • Medullary collecting ducts • Papillary collecting ducts
Inner medullary collecting duct cells	Medullary collecting ducts

Because the two most common types of cells in the collecting duct system are principal cells and intercalated cells, this discussion is limited to these 2.

The Principal Cells of the Collecting Duct System

These cells are responsible for the **mediation of the collecting ducts' influence on sodium and potassium homeostasis** via sodium and potassium channels. The channels are found on the apical membrane.

Aldosterone regulates the expression of sodium channels by the principal cells. Increased levels of the hormone aldosterone result in increased expression of sodium channels. Na/K-ATPase pump expression also is regulated by aldosterone. Therefore, an elevated level of aldosterone would result in increased absorption of sodium and secretion of potassium by the principal cells of the collecting duct system.

The principal cells also express aquaporin channels, which allow water to pass through the principal cells. These channels' expression is regulated by vasopressin. Therefore, both aldosterone and vasopressin regulate water and electrolyte homeostasis by the principal cells.

The Intercalated Cells of the Collecting Duct System

The intercalated cells can be classified into alpha and beta. They are **responsible for acid-base homeostasis.** Therefore, to emphasize, the principal cells are responsible for water and electrolyte homeostasis, whereas the intercalated cells are involved in acid-base homeostasis.

Alpha-intercalated cells have apical H-ATPase and H/K exchanger channels or pumps. The pumps are responsible for the secretion of hydrogen ions. They are involved when apatient develops a state of acidosis. The alpha-intercalated cells reabsorb bicarbonate via band 3, which is part of the Cl/HCO3 exchanger. Damage to the alpha-intercalated cells' ability to secrete hydrogen ions results in distal renal tubular acidosis, which is known as renal tubular acidosis type I or classical renal tubular acidosis.

Beta-intercalated cells, on the other hand, are responsible for secretion of bicarbonate via a specialized apical Cl/HCO3 exchanger known as pendrin. They reabsorb hydrogen ions via basal H/ATPase. Clearly, these cells are responsible for acid-base homeostasis in the case of alkalosis.

Balance in the function of both types of intercalated cells results in a state of physiologic acid-base homeostasis.

Water Absorption in the Collecting Duct System

An important note about water absorption in the collecting duct system must be emphasized. The osmotic gradient created by the countercurrent multiplier system in the Loop of Henle provides the force responsible for water reabsorption through the collecting ducts. The rate of osmotic movement is determined largely by the permeability of collecting ducts to water, and it is directly proportional to the number of aquaporins in the collecting duct epithelial cells.

Therefore, this gives ADH its main role in collecting ducts, which is to facilitate transportation of aquaporin 2 from storage vesicles in the cytoplasm to the plasma membrane, achieved when ADH binds to its membrane receptors on collecting ducts to stimulate the fusion of aquaporin 2 with the membrane. This leads to increased permeability of the collecting ducts and a resulting increase in the number of aquaporin 2 channels in the epithelial cells.

Insufficient ADH leads to dissociation of water channels via endocytosis.

Responsibilities of the collecting duct system

- Reabsorbs as much as 24% of filtered water in renal filtrate in the case of severe dehydration
- Impermeable to water without the presence of ADH

Therefore, if ADH is absent, a patient will develop diuresis.

Notes