

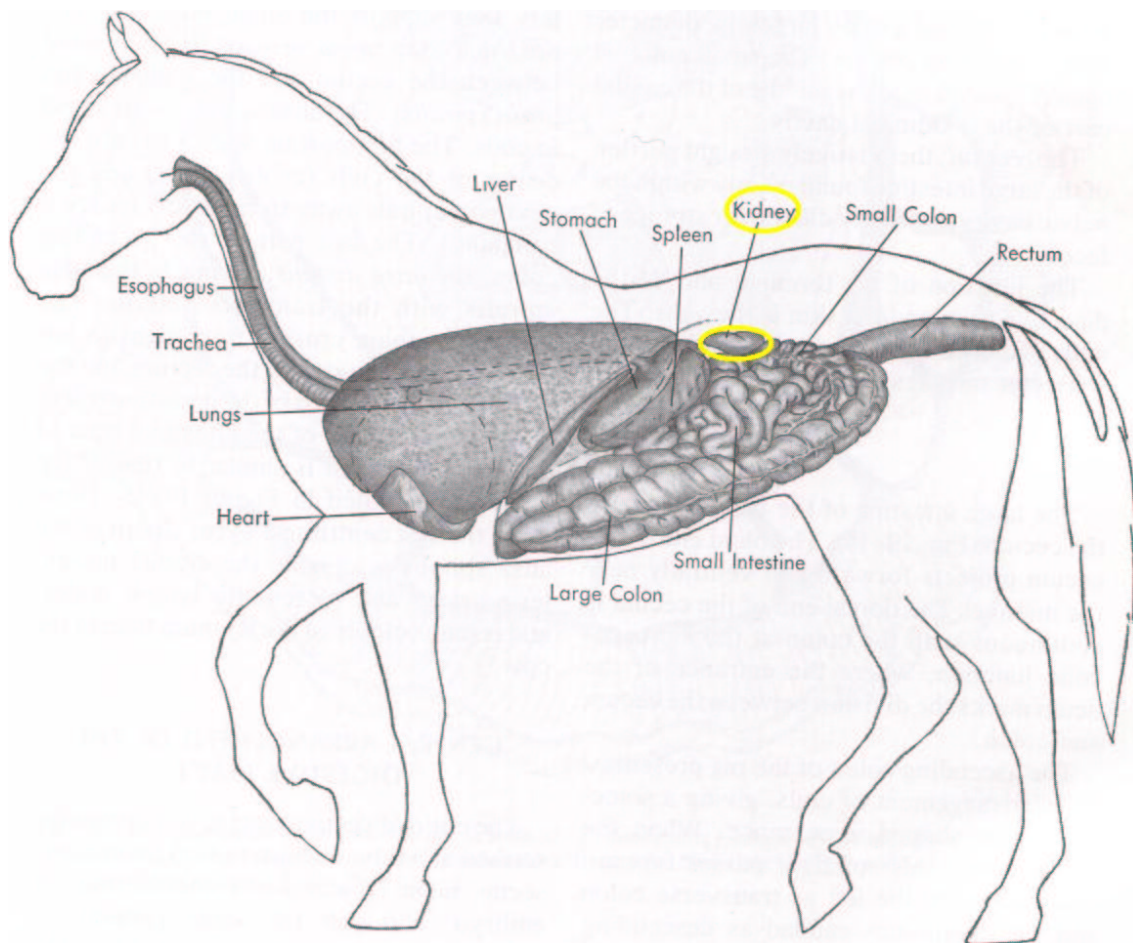
**Kidney**  
**ANS 215**  
**Physiology and Anatomy of**  
**Domesticated Animals**

**I. Primary Functions**

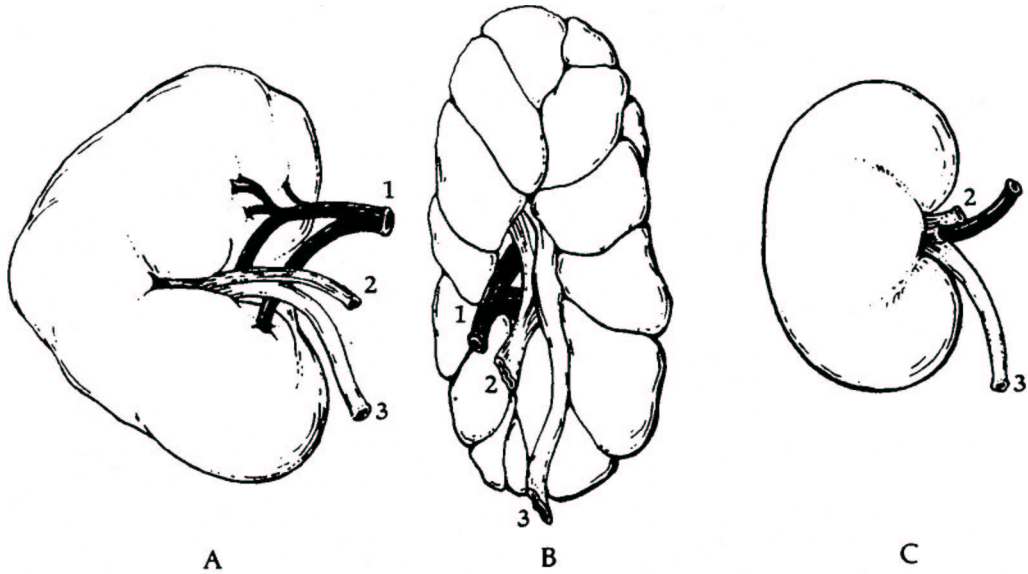
- A. Excretion of metabolic waste
- B. Regulation of the volume and composition of extracellular fluid

**II. Structure**

- A. Paired organs suspended from the dorsal abdominal wall by a peritoneal fold and blood vessels
  - 1. Slightly cranial to the midlumbar region

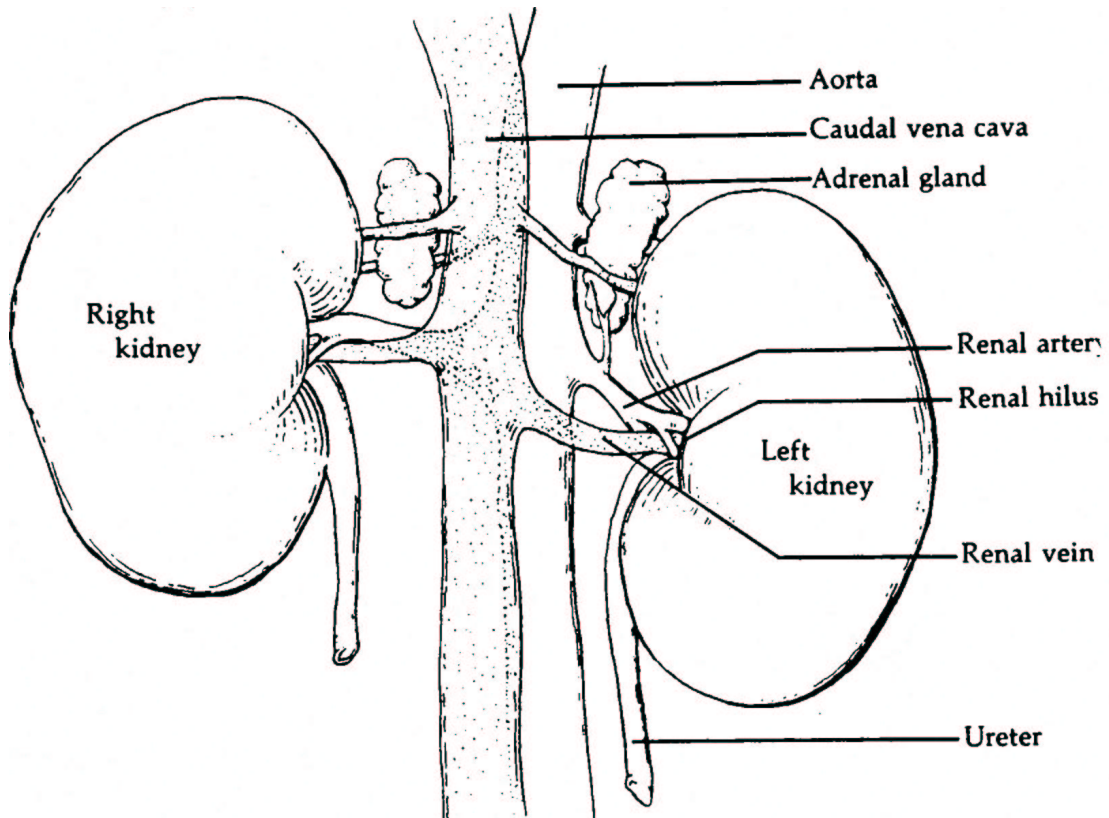


- B. Because they are separated from the abdominal cavity by their envelopment of peritoneum, they are called retroperitoneal structures.
- C. Blood is carried to each kidney by a renal artery arising from the abdominal aorta and carried away by the renal vein which empties into the caudal vena cava.



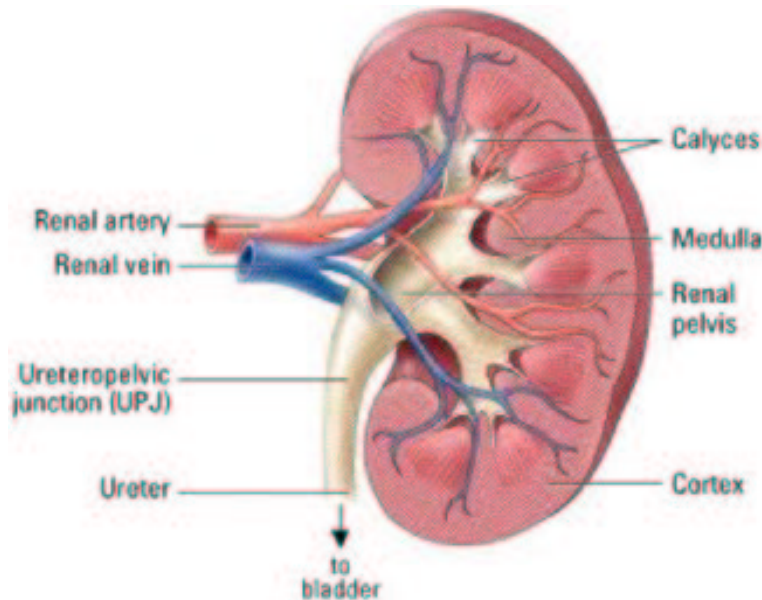
Right kidney, ventral vie. A. Horse, B. Cow, C. Sheep. These represent heart-shape, lobulated, and bean-shaped kidneys, respectively. 1. Renal artery, 2. Renal vein, 3. Ureter.

1. Bean shaped for most domestic animals, but is heart shaped in the horse and lobulated in cattle

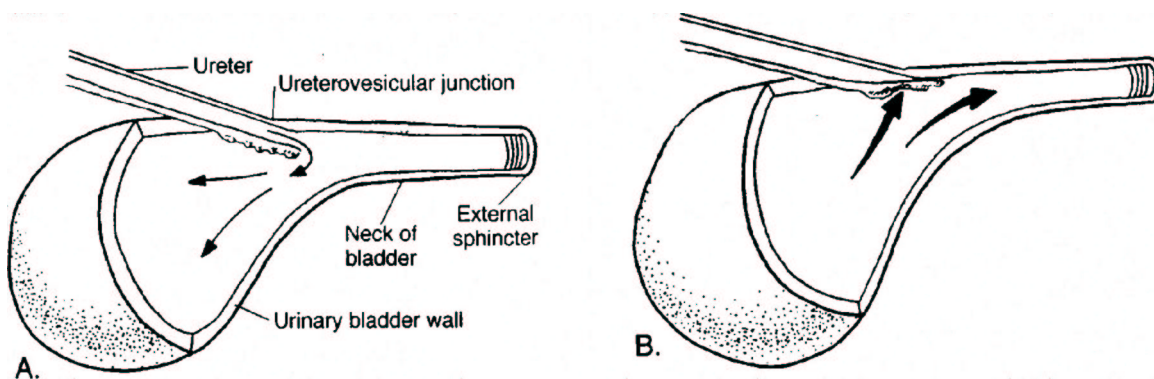


Ventral view of canine kidneys showing renal arteries, veins, and ureters and their portions relative to the aorta, vena cava, and adrenal glands.

2. Cross-section shows an outer cortex and inner medulla



3. Striations of the medulla are formed by the anatomic arrangement of the major parts that occupy the medulla, the loop of Henle of long-looped nephrons and the medullary portions of the collecting tubules (collecting ducts).
4. Renal hilus is the indented area on the concave edge of the kidney through which the ureter, blood vessels, nerves, and lymphatics enter or leave.
5. Renal pelvis is the expanded origin of the ureter in the kidney
6. Principal nerve supply to the kidney is sympathetic and fibers terminate mostly on glomerular arterioles.
7. The ureter is a smooth muscle tube that conveys urine from the renal pelvis to the urinary bladder.
8. The ureter enters the bladder at an oblique angle, the uterovesicular junction, thus forming a functional valve to prevent backflow when the bladder is filling



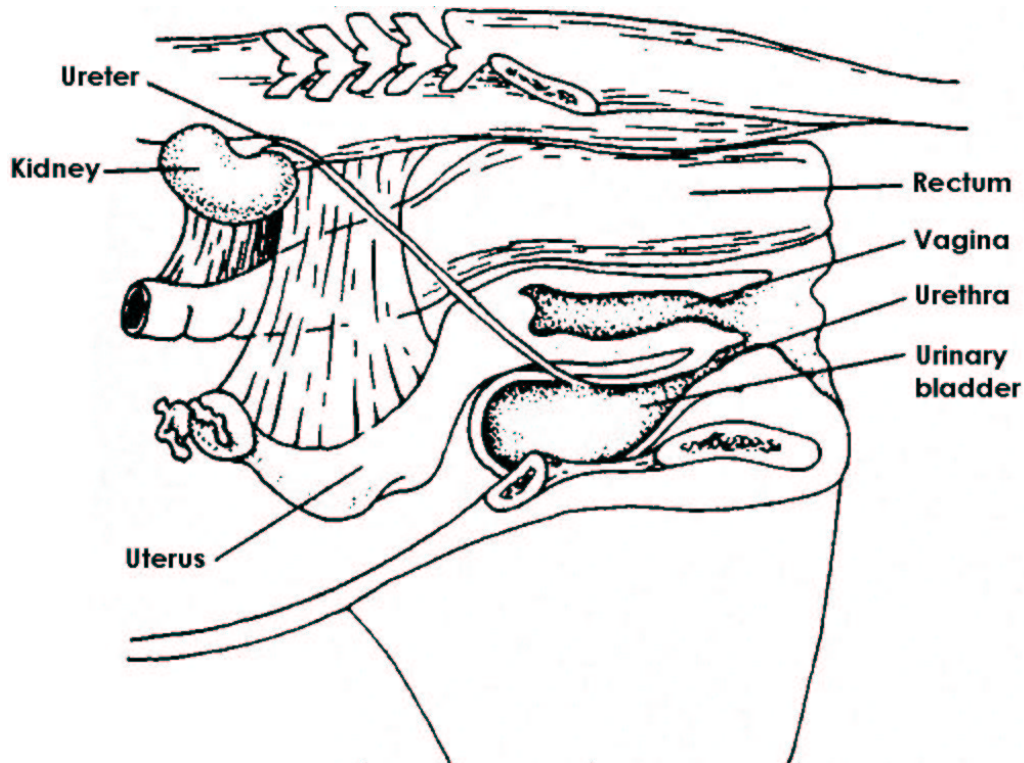
9. The urinary bladder is a hollow, smooth muscle organ that varies in size

depending on volume of urine.

- a. Smooth muscle of urinary bladder is known as the detrusor muscle
- b. Epithelial cell lining of the bladder accommodates for the change in size and is known as transitional epithelium.
- c. The urethra is the caudal continuation of the neck of the bladder leading to the outside of the body.

10. Prevention of urine escape while the bladder is filling is provided by contraction of the external sphincter.

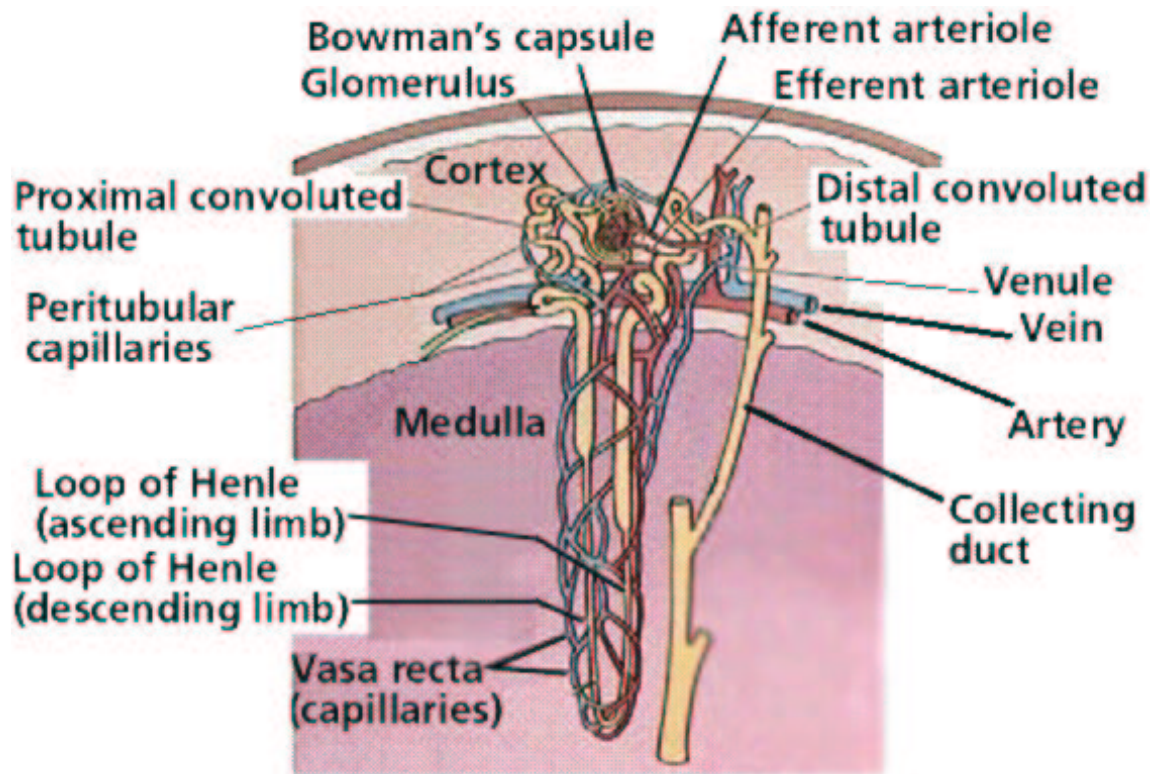
- a. skeletal muscle that encircles the urethra at this point
- b. When urine is expelled from the bladder, the external sphincter relaxes and the bladder muscles contract.



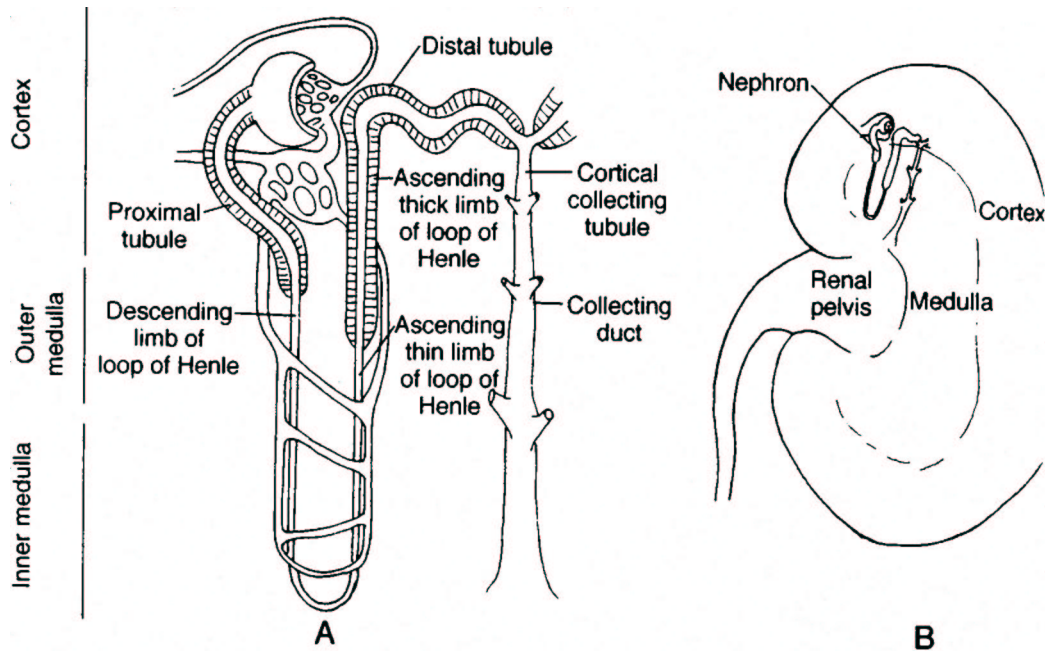
Midsagittal section of the cow pelvis showing positions of the urinary bladder and urethra relative to other organs.

### III. Microstructure

- A. Functional unit of the kidney is the nephron

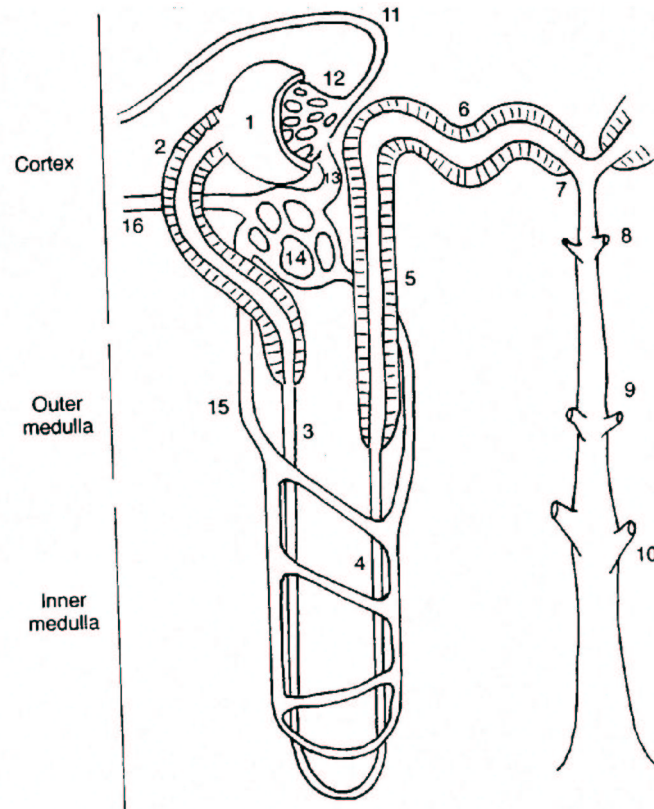


- B. Two principal types of nephron are present in the kidney identified by:
1. Location of their glomeruli
  2. The depth of penetration of the loops of Henle
    - a. Nephrons with glomeruli in outer and middle cortex are cortical and corticomedullary nephrons.
    - b. Nephrons with glomeruli close to the medulla and have loops of Henle that extend more deeply into the medulla are juxtamedullary nephrons



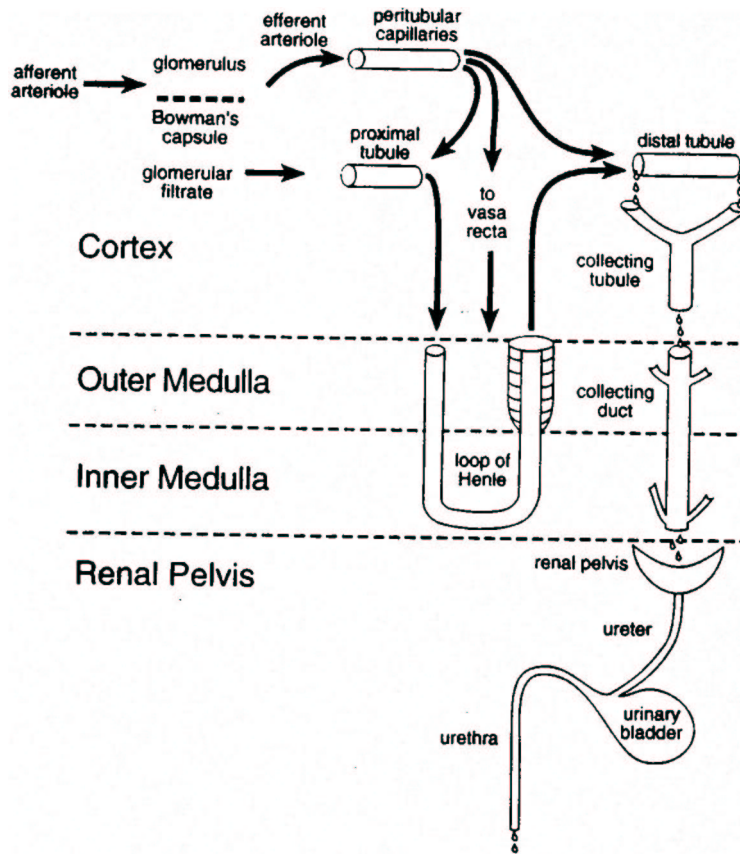
A. Component parts of a juxtamedullary nephron (mammalian) relative to their locations in the cortex and medulla. B. Midsagittal section of the kidney showing the location of a juxtamedullary nephron (exaggerated size) relative to the cortex, medulla, and renal pelvis.

- C. Glomerulus is the tuft of capillaries through which filtration is accomplished
1. Afferent arteriole conducts blood to the glomerulus
  2. Efferent arteriole conducts blood away from the glomerulus
  3. Blood leaving through efferent arterioles is redistributed into another capillary bed known as the peritubular capillaries
  4. Vasa recta are capillary branches from the peritubular capillaries associated with the long-looped nephrons.
  5. After perfusing the kidney the blood leaves by the renal vein.
- D. Filtrate from the glomerulus is collected by Bowmans capsule and is subsequently directed through the proximal tubule, loop of Henle, and distal tubule.



The functional nephron with blood supply. 1. Bowman's capsule, 2. proximal tubule, 3. descending limb of loop of Henle, 4. thin ascending limb of loop of Henle, 5. thick ascending limb of loop of Henle, 6. distal tubule, 7. connecting tube, 8. cortical collecting tubule, 9. outer medullary collecting duct, 10. inner medullary collecting duct, 11. afferent arteriole, 12. glomerulus, 13. efferent arteriole, 14. peritubular capillaries, 15. vasa recta, 16. to renal vein.

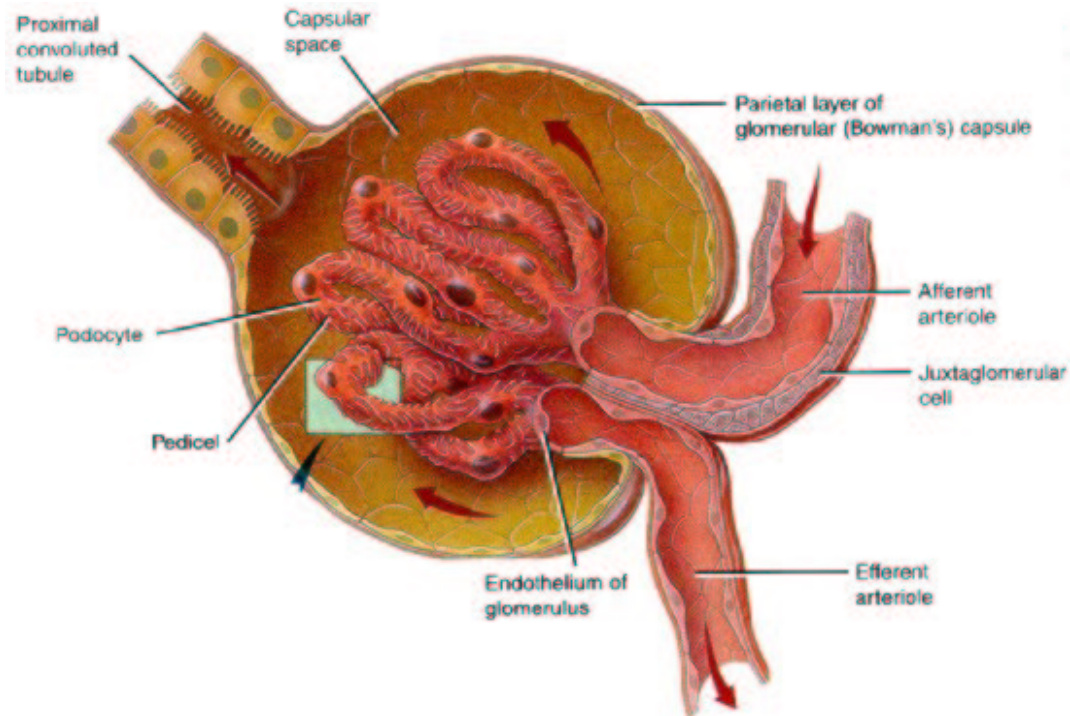
- E. The distal tubule enters into the cortical collecting tubule
  - 1. receives fluid from several distal tubules
- F. When the collecting tubule turns away from the cortex and passes down the medulla, it is known as a collecting duct.
- G. Successive generations of collecting ducts coalesce to form larger collecting ducts.
- H. The tubular fluid is finally discharged from the larger collecting ducts into the pelvis of the kidney, and it is conveyed from there by the ureters to the urinary bladder for storage until discharge through the urethra.



Summary of kidney blood flow and tubular fluid flow as it applies to the nephron. After removal of the filtration fraction of plasma at the glomerulus, the remaining blood that enters the efferent arteriole is distributed to the nephron as shown. The fraction of plasma filtered at the glomerulus enters Bowman's capsule as glomerular filtrate. It continues through the nephron tubules and ducts as tubular fluid. The tubular fluid is subjected to reabsorption and secretion and enters the renal pelvis as urine. Urine is finally evacuated from the bladder by micturition.

- I. The loop of Henle is composed of three segments which differ in thickness due to differences in the epithelial cells and not to changes in lumen diameter.
  1. thin descending limb
  2. thin ascending limb
  3. thick ascending limb
- J. The junction of the distal tubule and glomerulus is known as the juxtaglomerular apparatus.
  1. There are characteristic cell types at this location.
  2. In the tubule, the cells are collectively known as the macular densa.
  3. In the afferent and efferent arterioles they are called the juxtaglomerular cells.
  4. The juxtaglomerular apparatus is associated with regulating the amount of blood flowing to the kidney, amount of filtration, and the secretion of rennin, an enzyme involved in the formation of angiotensin II.

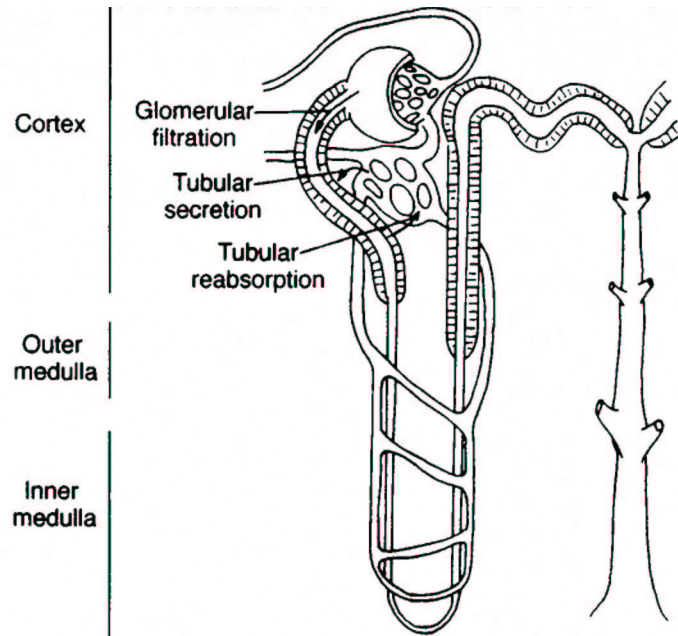




#### IV. Formation of Urine

A. Three processes involved in urine formation:

1. Glomerular filtration
  - a. produces filtrate of plasma known as glomerular filtrate
  - b. first appears in Bowman's capsule
  - c. becomes tubular fluid when it enters nephron tubules, because of compositional changes as a result of reabsorption from tubular lumen
2. Tubular reabsorption
  - a. continues through length of nephron and collecting duct
  - b. directed from tubules into peritubular capillaries
3. Tubular secretion
  - a. continues through length of nephron and collecting duct
  - b. directed from peritubular capillaries into tubules



Functional nephron and processes involved in urine formation. The arrows indicate the origins and destinations of the three processes associated with the formation of urine. Following glomerular filtration, glomerular filtrate enters the proximal tubule and becomes tubular fluid. Tubular secretion is directed from the peritubular capillaries into the tubules and tubular reabsorption is directed from the tubules into the peritubular capillaries. Tubular reabsorption and tubular secretion occur throughout the length of the nephron.

## V. Distribution of Blood at the Glomerulus

- A. Renal blood flow (RBF) refers to the rate at which blood flows to the kidneys (ml/min.)
- B. Renal plasma flow (RPF) refers to that part of the RBF that is plasma
- C. As long as there is RBF, there will be filtration at the glomerulus and a filtrate will be formed.
  1. rate of formation is known as glomerular filtration rate (GFR)
  2. ratio of GFR to RPF is known as filtration fraction (i.e. that fraction of RPF that becomes glomerular filtrate)
- D. GFR can be varied by changing the diameter of the afferent or efferent arteriole.
  1. Dilation of the afferent arteriole increases blood flow, which increases hydrostatic pressure and the potential for filtration.
  2. Constriction of the efferent arteriole increases the glomerular hydrostatic pressure, thus increasing the potential for filtration.

## Approximate Values for Several Kidney Function Variables

**in a 11.35kg (25 lb) Dog in a Normal State of Hydration**

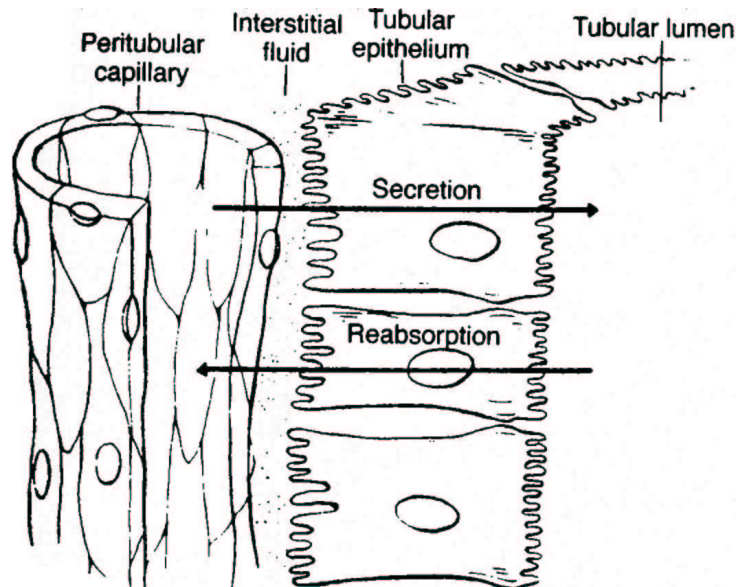
| <b>Variable</b>                                | <b>Value</b> |
|--|--------------|
| Cardiac output (ml/min)                        | 1500         |
| Blood flow to kidneys<br>(% of cardiac output) | 20           |
| Renal blood flow (ml/min)                      | 300          |
| Renal plasma flow (ml/min)                     | 180          |
| Glomerular filtration rate (ml/min)            | 45           |
| Filtration fraction (decimal equivalent)       | 0.25         |
| Urine volume in 24h <sup>†</sup> (ml)          | 681          |
| Glomerular filtrate volume in 24h (ml)         | 64800        |
| Volume of urine as percent of filtrate         | 1.05         |
| Filtrate reabsorbed (%)                        | 98.95        |

\* Based upon plasma portion of hematocrit being approximately 60%

<sup>†</sup> Calculated from average rate for dogs being 60 ml/kg/24 hr.

## VI. Tubular Reabsorption and Secretion

- A. For reabsorption to occur, a substance must pass from the tubular lumen through the epithelial cells, diffuse through the interstitial fluid, and enter the plasma.

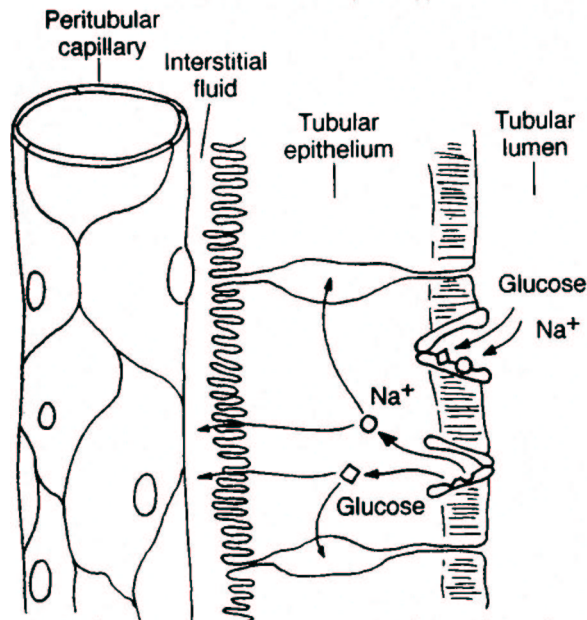


Functional nephron and processes involved in urine formation. The arrows indicate the origins and destinations of the three processes associated with the formation of urine. Following glomerular filtration, glomerular filtrate enters the proximal tubule and becomes tubular fluid. Tubular secretion is directed from the peritubular capillaries into the tubules and tubular reabsorption is directed from the tubules into the peritubular capillaries. Tubular reabsorption and tubular secretion occur throughout the length of the nephron.

- B. To prevent loss of compounds important to body function such as glucose and

amino acids, they are reabsorbed from the filtrate by the epithelial cells in the proximal convoluted tubules and are transported into the interstitial fluid.

1. The transport process couples sodium transport with glucose and amino acid transport.
2. Removal of sodium, glucose, and amino acids from the lumen into the interstitial fluid and capillaries increases the concentration of water in the lumen and water is reabsorbed by osmosis into the interstitial fluid and capillaries.



Transport of  $\text{Na}^+$  from tubular lumen into the tubular epithelial cell and its cotransport with glucose. The protein carrier conformation permits reception of  $\text{Na}^+$  and glucose from the lumen. Carrier conformational change permits  $\text{Na}^+$  and glucose release into the epithelial cytoplasm. Once released the carrier returns to its original conformation for the reception of more  $\text{Na}^+$  and glucose. The  $\text{Na}^+$  released into the tubular epithelial cytoplasm is actively transported through the basal and lateral borders of the cells into the interstitial fluid and diffuses from there into the capillaries. Glucose follows the same pathways except that it is not actively transported. Amino acids are also cotransported with  $\text{Na}^+$  similar to that of glucose.

3. The secretion of  $\text{H}^+$  occurs throughout the length of the nephron tubules and is coupled with the reabsorption of  $\text{HCO}_3^-$ .
4. The secretion of  $\text{K}^+$  occurs in the distal convoluted tubule, collecting tubules and ducts, and is coupled with the reabsorption of  $\text{Na}^+$ .

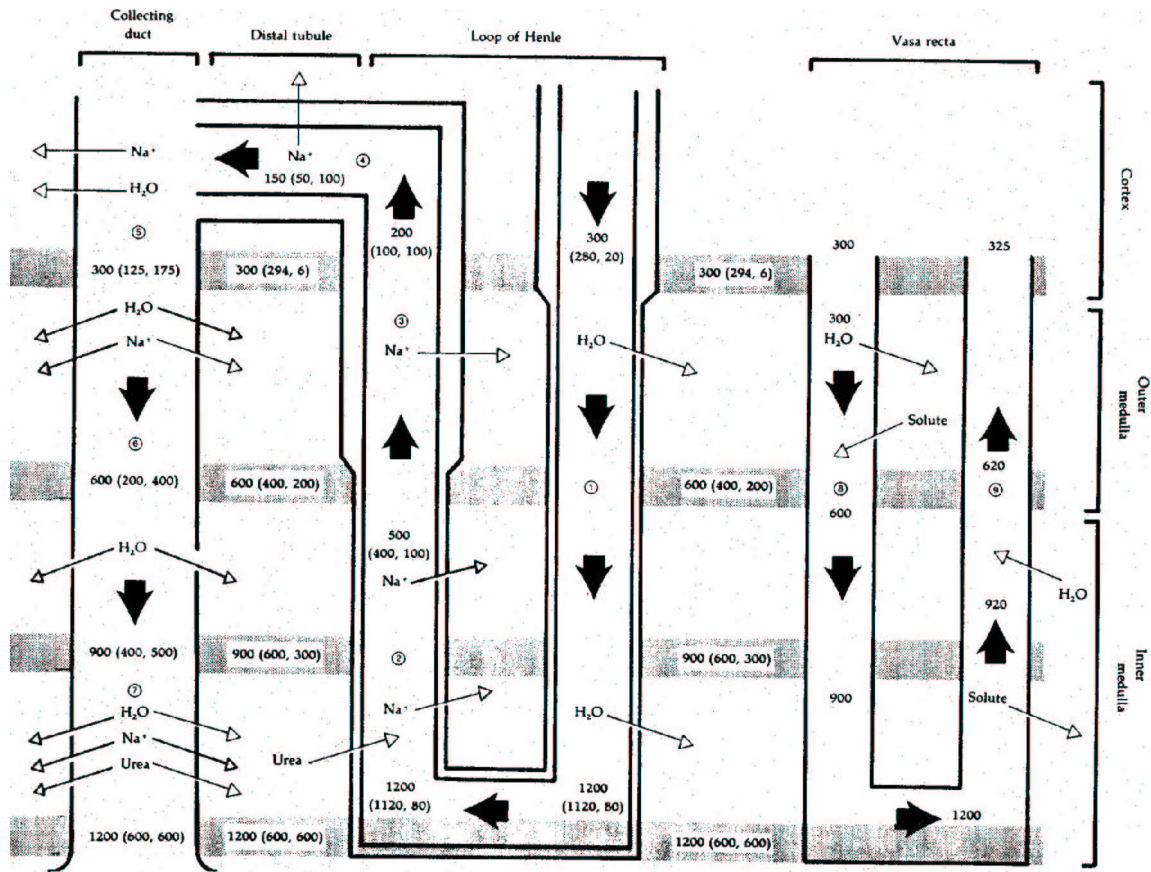
#### C. Transport maximum

1. When the transport maximum is exceeded, the substance will appear in the urine.
2. Each nephron has a different transport maximum, therefore the substance can appear in the urine before the transport maximum for the kidney is reached.
  - a. renal threshold – when a substance first appears in the urine
  - b. renal threshold for glucose is 180 mg/dl

#### D. Countercurrent mechanism

1. tubular phenomenon

2. associated with the loop of Henle of the long-looped nephrons

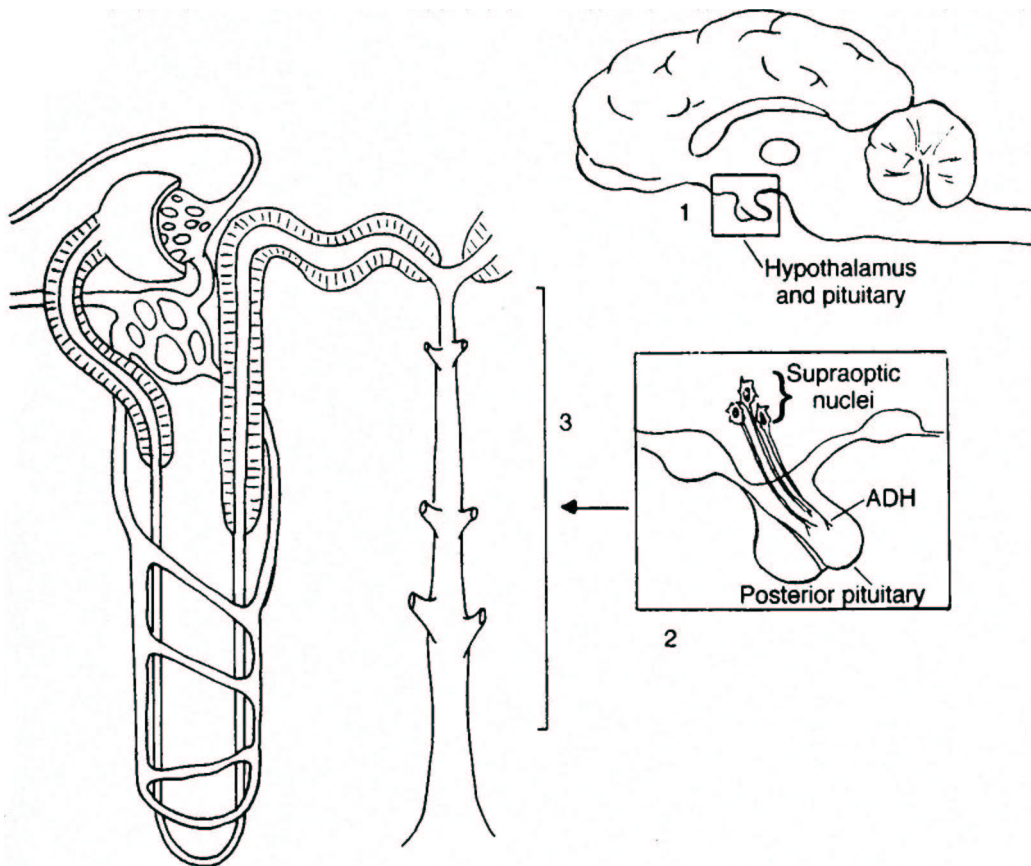


3. increases the solute (NaCl and urea) concentration in the interstitial fluid of the kidney medulla
4. permits perfusion of the medulla with blood without removing the high solute concentration that was established

## VII. Hormones and Kidney Function

### A. Antidiuretic Hormone

1. Affects permeability of epithelial cells for water
  - a. increased levels decrease permeability
2. Secreted from the posterior pituitary in response to dehydration



Relationships among the hypothalamus, posterior pituitary, and kidneys in the regulation of extracellular hydration. 1. Extracellular dehydration detected by osmoreception in the hypothalamus. Boxed area in 1 shows location in the brain of the boxed area in 2. 2. ADH (neurosecretion of supraoptic nuclei in hypothalamus) secreted into blood in response to dehydration. 3. Cortical collecting tubules and medullary collecting ducts are targets of ADH.

3. Cortical collecting tubules and medullary collecting ducts are the targets of ADH, causing increased reabsorption of H<sub>2</sub>O.
4. The thicker the medulla (longer loops of Henle and collecting ducts), the more concentrated the urine.
5. ADH secretion is affected by blood volume, cold, and alcohol.

**Relationship of Structure to Concentrating Capacity in Mammalian Kidneys**

| Animal       | Kidney size* (mm) | Long-looped nephrons (%) | Relative medullary thickness† | Maximum freezing point depression in urine (°C) |
|--------------|-------------------|--------------------------|-------------------------------|---|
| Beaver       | 36                | 0                        | 1.3                           | 0.96  |
| Pig          | 66                | 3                        | 1.6                           | 2   |
| Human        | 64                | 14                       | 3                             | 2.6   |
| Dog‡         | 40                | 100                      | 4.3                           | 4.85  |
| Cat          | 24                | 100                      | 4.8                           | 5.8   |
| Rat          | 14                | 28                       | 5.8                           | 4.85  |
| Kangaroo rat | 5.9               | 27                       | 8.5                           | 10.4  |
| Jerboa       | 4.5               | 33                       | 9.3                           | 12  |
| Psammomys    | 13                | 100                      | 10.7                          | 9.2   |

**B. Angiotensin II**

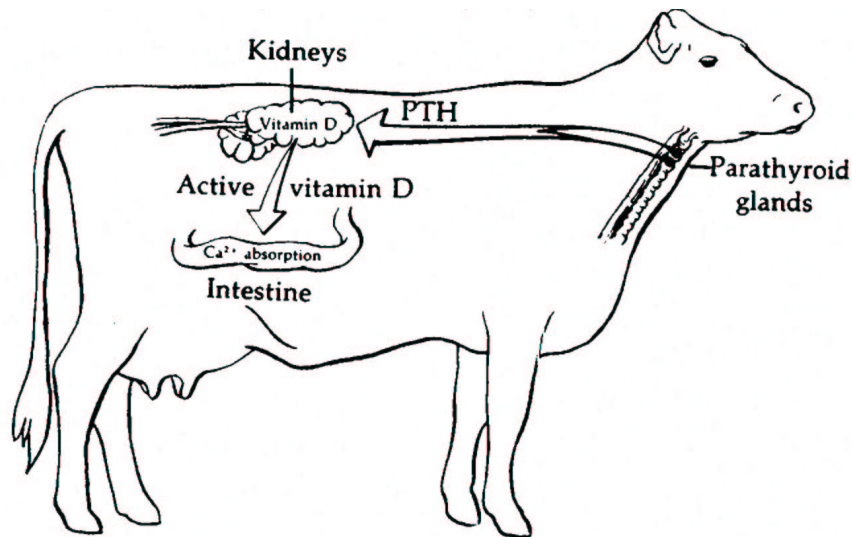
1. Ensures a continuous GFR by increasing the FF when the RBF decreases (net effect is to increase plasma volume and blood pressure).
2. Also causes peripheral vasoconstriction.

**C. Aldosterone**

1. Involved in regulation of  $K^+$  concentration of extracellular fluid and is produced in adrenal glands.
2. Promotes secretion of  $K^+$  ions and reabsorption of  $Na^+$  ions.
3. The net effect is an increases plasma volume.

**D. Parathyroid Hormone**

1. secreted by parathyroid glands
2. Acts on the kidney to increase reabsorption of  $Ca^{2+}$  and promotes excretion of phosphorus.
3. Vitamin D is also activated by the kidney to increase absorption of calcium from the intestine.



Relationship of parathyroid hormone (PTH), the kidneys, and calcium iron homeostasis in the cow. PTH from the parathyroid gland activates vitamin D in the kidney; activated vitamin D promotes absorption of  $Ca^{2+}$  from the intestine

### VIII. Micturation

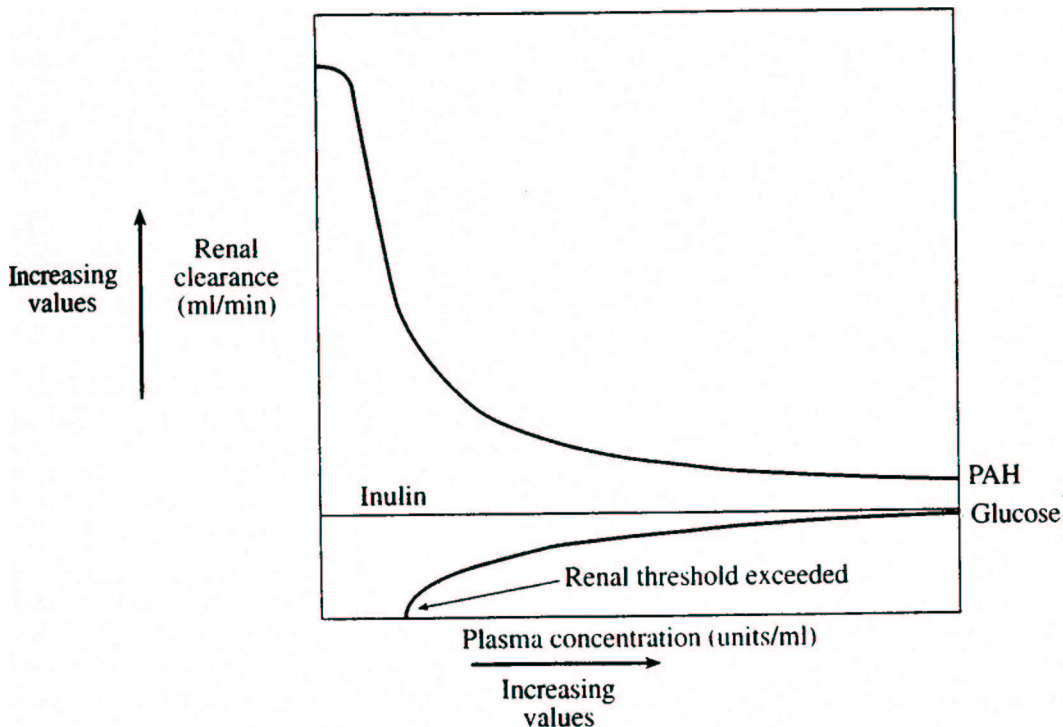
- A. During formation of urine, the tubular fluid flows through the tubules because of a hydrostatic pressure difference between Bowman's capsule and kidney pelvis.
- B. Urine is transported from the renal pelvis to the urinary bladder by peristalsis in the ureters.
- C. Micturation is the physiologic term for emptying the bladder.
- D. Reflexes controlling the emptying of the bladder are in the sacral spinal cord and brain stem.
- E. Parasympathetics are the sole motor nerve supply to the detrusor muscle of the bladder.

### IX. Characteristics of Mammalian Urine

- A. Composition – varies on physiologic state
- B. Color – yellow due to bilirubin
- C. Odor – influenced by diet
- D. Consistency – syrupy in the horse due to mucus
- E. Nitrogenous component – urea

### X. Renal Clearance

- A. Measurement of the kidney's ability to remove substances from the plasma
- B. Varies by substance depending on reabsorption and secretion

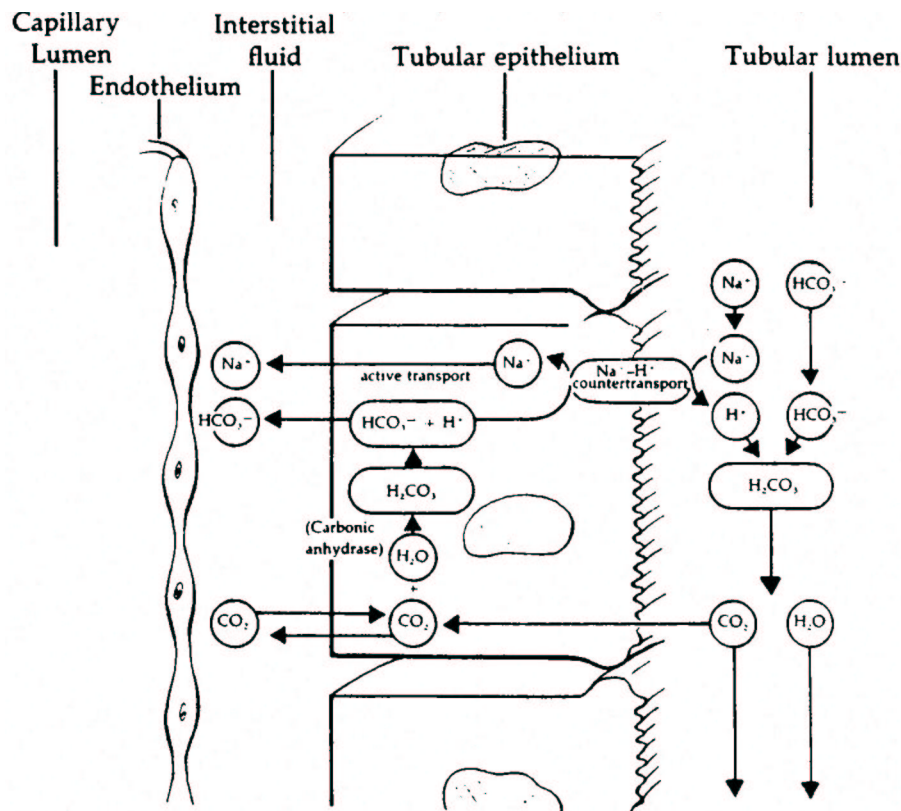


Effect of tubular reabsorption and tubular secretion of renal clearance. Glucose represents a substance that is reabsorbed from the tubules. p-aminohippuric acid (PAH) represents a substance that is secreted into the tubule but not reabsorbed, and inulin represents a substance that is neither reabsorbed nor secreted by the renal tubules. All of these substances are freely filtered at the glomerulus and enter the tubules. The decrease for renal clearance of PAH and the increase of renal clearance for glucose indicates a point at which their renal clearance is changed as their plasma concentration increases.



## XI. Regulation of Acid-Base Balance – Bicarbonate System

- A. Hydration of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  occurs in the cytoplasm of the epithelial cell ( $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$ ) and is accelerated by the enzyme carbonic anhydrase.
- B. After hydration the  $\text{H}^+$  formed is secreted into the tubular lumen in exchange for  $\text{Na}^+$ .
- C. The  $\text{H}^+$  that is secreted combines with the bicarbonate tubular buffer to form  $\text{H}_2\text{CO}_3$ , which is further dehydrated to  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .
- D. The  $\text{HCO}_3^-$  formed from hydration within the cell diffuses into the extracellular fluid accompanied by the  $\text{Na}^+$  exchanged for the  $\text{H}^+$
- E. The exchange of  $\text{H}^+$  and  $\text{HCO}_3^-$  balances the pH.



Mechanism for the renal secretion of  $\text{H}^+$  associated with the bicarbonate buffer system in the tubular fluid.

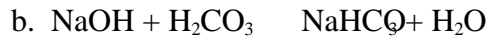
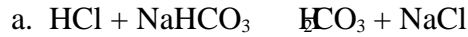
## XII. Maintenance of Acid-Base Balance – Respiratory System

- A. Equally important to bicarbonate system is the respiratory system.
- B. During transport to the lungs,  $\text{CO}_2$  diffuses into the erythrocytes and is hydrated under the influence of carbonic anhydrase.
  1. The  $\text{H}^+$  that is formed is buffered, and  $\text{HCO}_3^-$  diffuses into the plasma.
- C. When blood passes through the pulmonary capillaries the diffusion of  $\text{CO}_2$  into the pulmonary alveoli increases and the hydration reaction is reversed quickly so that  $\text{H}^+$  is lost from the extracellular fluid.

### XIII. Chemical Buffer Systems

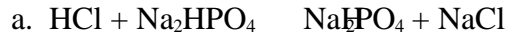
A. First line of defense in maintaining constant pH of the extracellular fluids.

1. Bicarbonat system

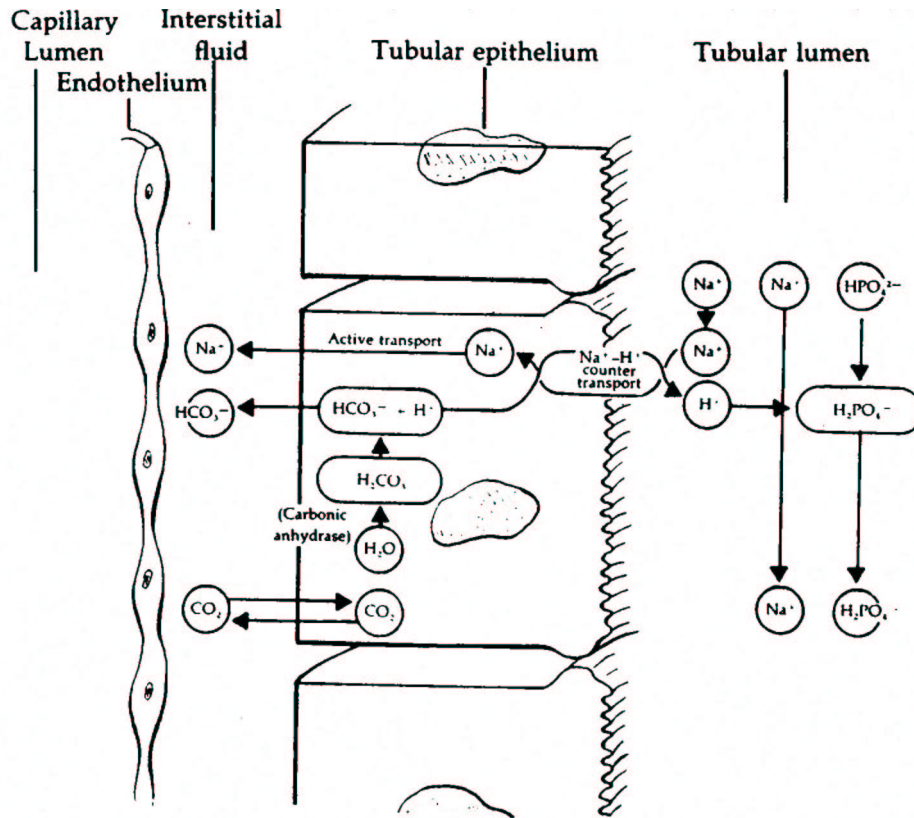


c. weak but unique, because it can be adjusted by the respiratory system and kidneys – extracellular buffer

2. Phosphate system



c. most important as intracellular buffer



Mechanism for the renal secretion of  $\text{H}^+$  associated with the phosphate buffer system in the tubular fluid.

3. Protein system

a. Positive and negative charges on proteins act as buffering agents.

b. good extracellular buffer

c. anemic individuals quickly become acidic on exertion

### XIV. Avian Renal Physiology

- A. Similarities to mammals.
  - 1. urine formation
  - 2. glomerular filtration
  - 3. tubular reabsorption and tubular secretion
- B. Differences
  - 1. Two major nephron types in birds
    - a. reptilian – lack loop of Henle (cannot concentrate urine)
    - b. mammalian
  - 2. presence of a renal portal system
  - 3. Formation of uric acid instead of urea
  - 4. postrenal modification of uretral urine