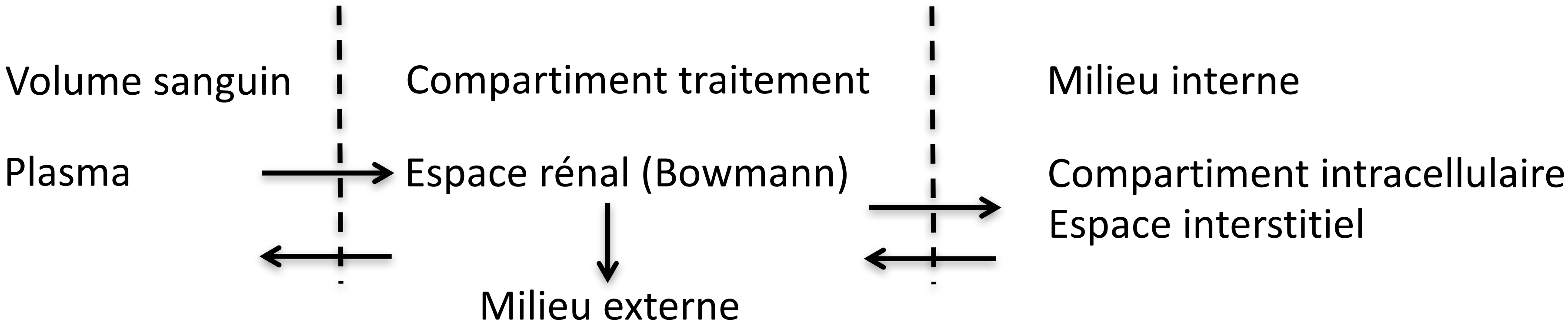
Système urinaire: principe général de la production d’urine

- 2 entités: 1) Production urine primaire
  2) Traitement → élimination de l’urine finale



Système urinaire Formation de l’urine par le rein 3 types de fonctions

Tubular Processing of the Glomerular Filtrate

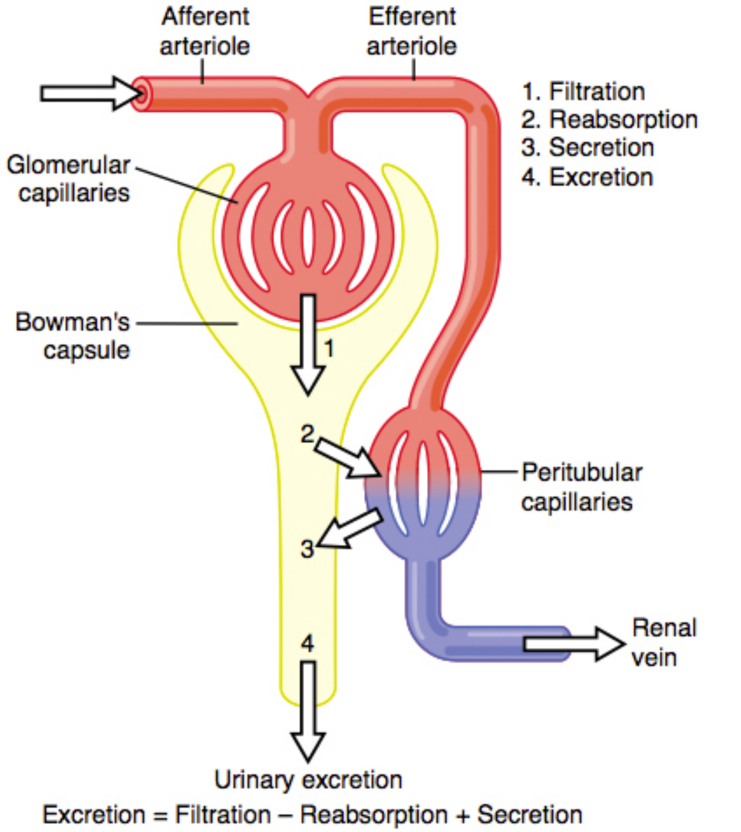


Figure 26–8

Basic kidney processes that determine the composition of the urine. Urinary excretion rate of a substance is equal to the rate at which the substance is filtered minus its reabsorption rate plus the rate at which it is secreted from the peritubular capillary blood into the tubules.

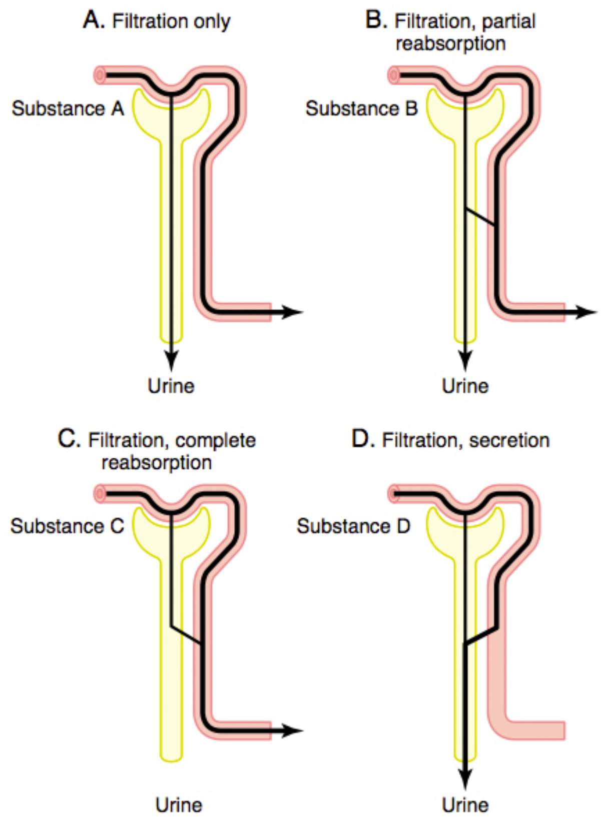


Figure 26–9

Renal handling of four hypothetical substances. *A*, The substance is freely filtered but not reabsorbed. *B*, The substance is freely filtered, but part of the filtered load is reabsorbed back in the blood. *C*, The substance is freely filtered but is not excreted in the urine because all the filtered substance is reabsorbed from the tubules into the blood. *D*, The substance is freely filtered and is not reabsorbed but is secreted from the peritubular capillary blood into the renal tubules.

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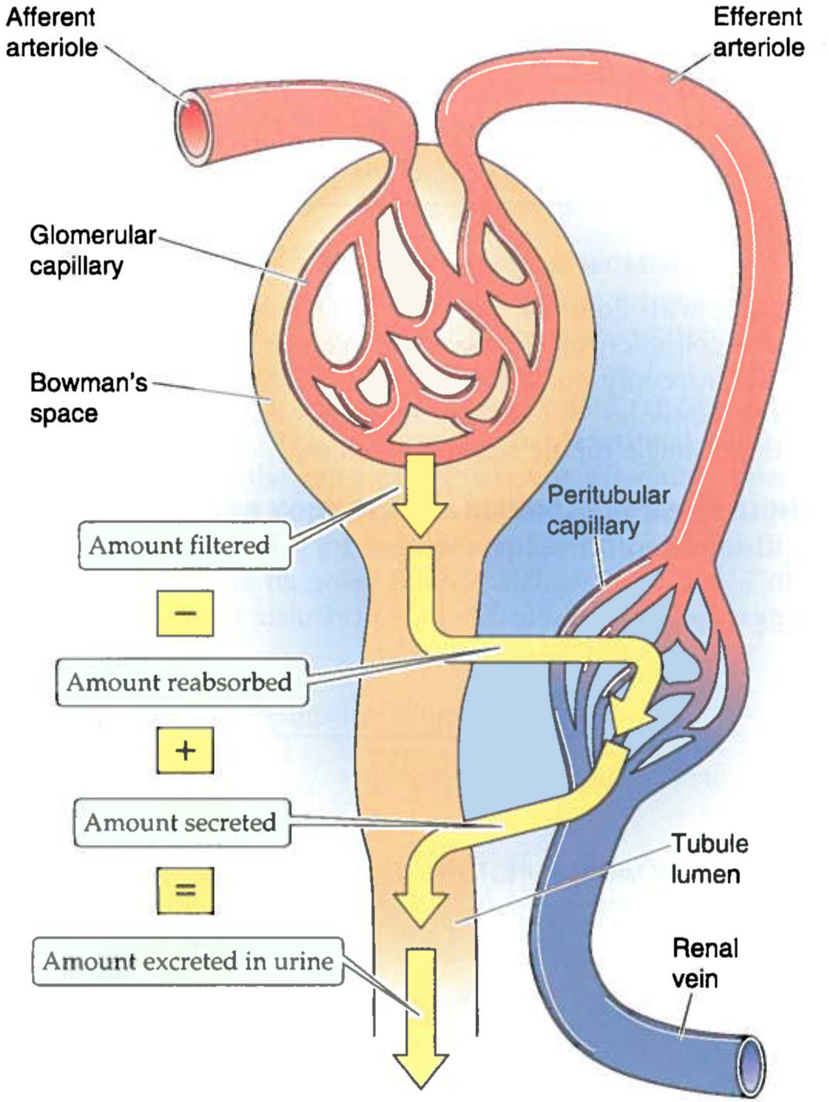
Système urinaire Formation de l'urine par le rein circulation de l'urine



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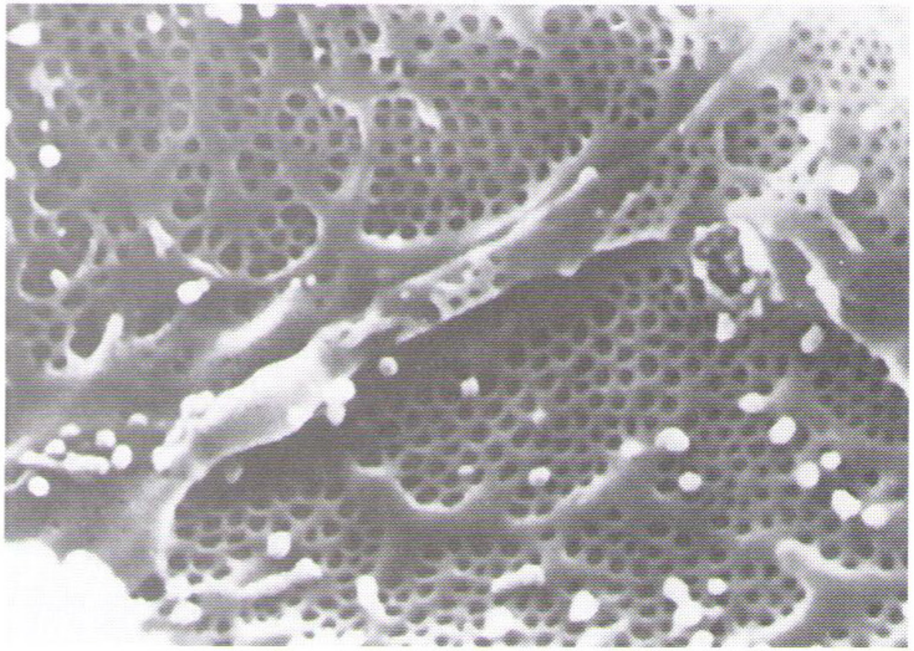
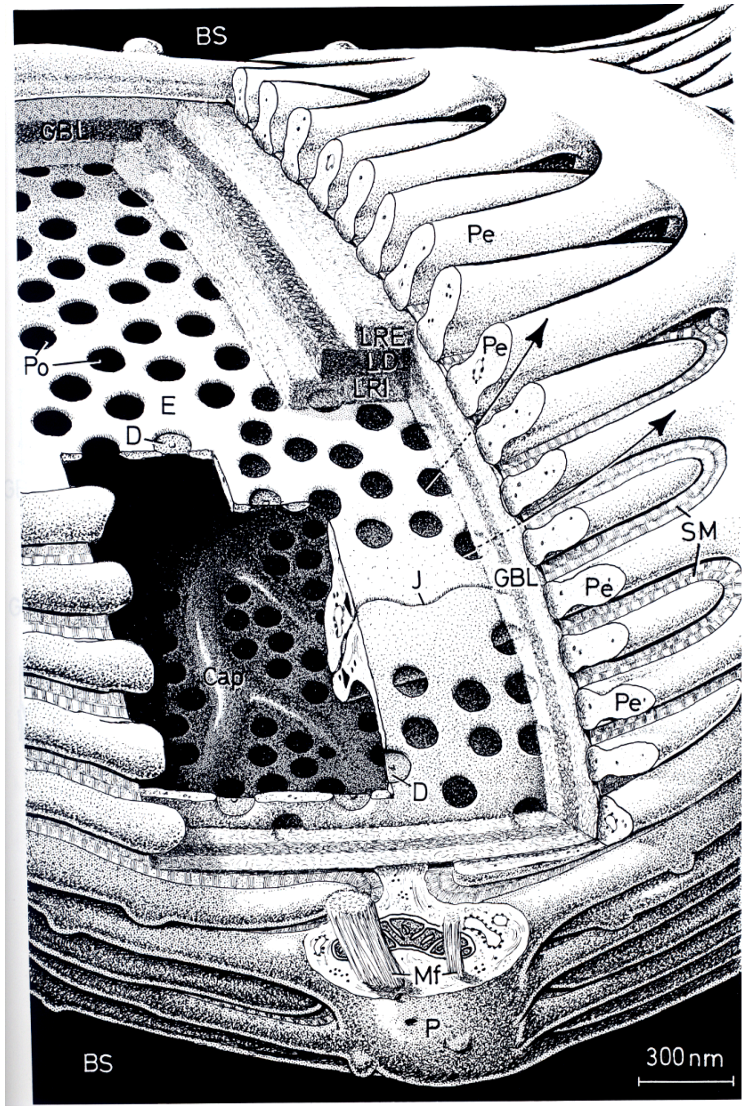
Système urinaire Filtration glomérulaire: 1ère étape de la formation de l'urine





Système urinaire Filtration glomérulaire: le rôle du GFR

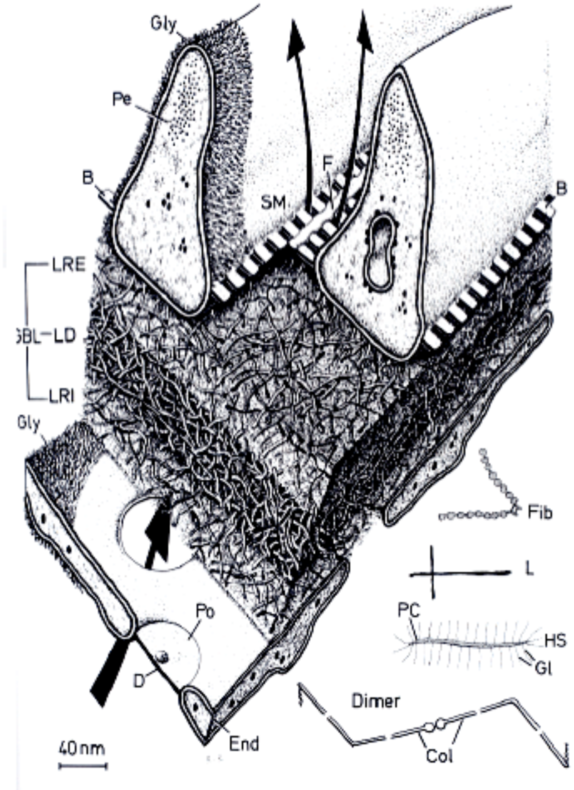
GFR Is about 20 % of the Renal Plasma Flow

***Glomerular capillary membrane* is essential to determine the filterability of solutes that is inversely related to their size.**

Table 26–1

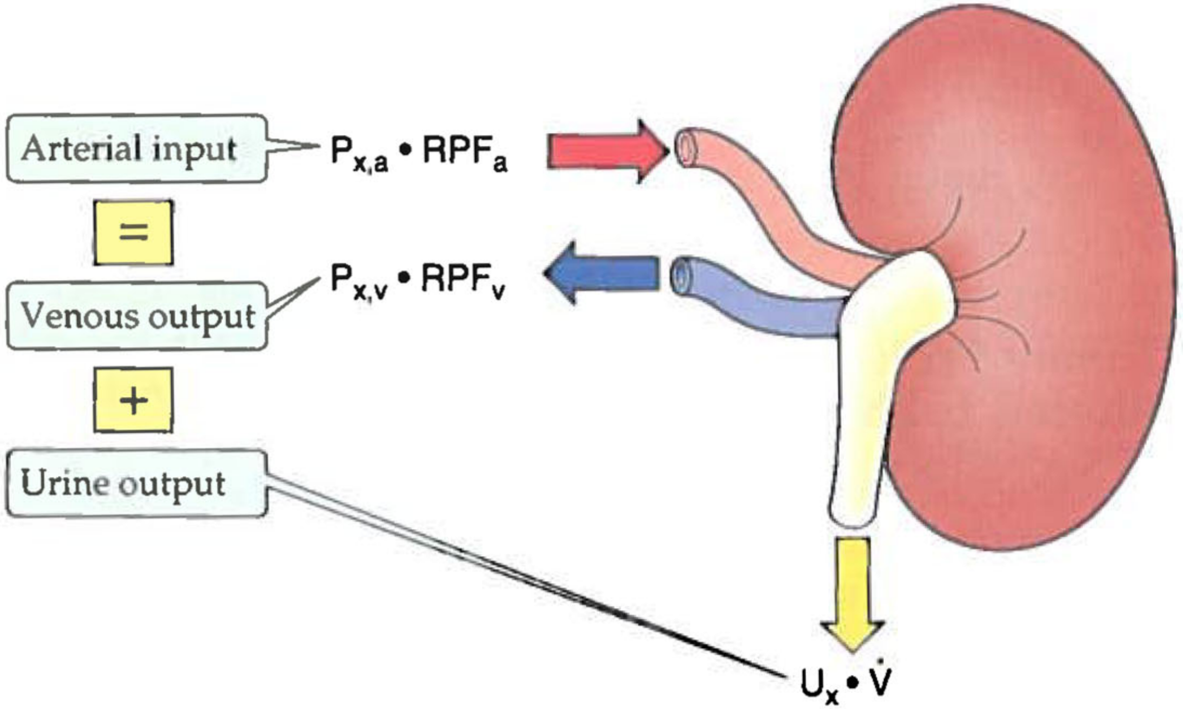
Filterability of Substances by Glomerular Capillaries Based on Molecular Weight

Substance	Molecular Weight	Filterability
Water	18	1.0
Sodium	23	1.0
Glucose	180	1.0
Inulin	5,500	1.0
Myoglobin	17,000	0.75
Albumin	69,000	0.005



Système urinaire Filtration glomérulaire: principe de continuité

FIGURE 32–8. Solute mass balance in the kidney.



Principe conservation de masse: entrée = sortie

$P_{x,a} \cdot RPF_a = P_{x,v} \cdot RPF_v + U_x \cdot \dot{V}$ entrée artérielle = sortie veineuse + sortie urinaire

Conc art. plasma_x · Renal plasma flow art = Conc vein. plasma_x · Renal plasma flow vein + Conc urinaire_x · débit urinaire

Système urinaire Filtration glomérulaire: les équations constitutives

$P_{x,a} \cdot RPF_a = P_{x,v} \cdot RPF_v + U_x \cdot \dot{V}$ entrée artérielle = sortie veineuse + sortie urinaire

Filtration idéale → $RPF_a = Clearance_x$ C_x = taux (''débit'') de filtration d'une substance X

Filtration idéale → sortie veineuse = 0 $P_{x,v} = 0$ totalement filtrée au passage glomérulaire

$P_{x,a} \cdot C_x = U_x \cdot \dot{V}$

$C_x = \frac{U_x \cdot \dot{V}}{P_{x,a}}$

Inuline: totalement filtrée; 0 réabsorption 0 sécrétion

$C_{In} = \frac{U_{In} \cdot \dot{V}}{P_{In}} = GFR$ 125 ml/min

Para-AminoHippuric acid: filtration+ sécrétion

$RPF = \frac{U_{PAH} \cdot \dot{V}}{P_{PAH} - V_{PAH}}$

$ERPF = \frac{U_{PAH} \cdot \dot{V}}{P_{PAH}} = C_{PAH}$

Inuline→ Créatinine: filtration; 0 réabsorption 0 sécrétion

$C_{Cré} = \frac{U_{Cré} \cdot \dot{V}}{P_{Cré}} \cong GFR$ 125 ml/min

RPF: renal plasma flow [ml/min]
V_{PAH}: venous concentration PAH [mg/ml]
ERPF: effective renal plasma flow [ml/min]

Système urinaire Déterminants du GFR sous l'effet de 4 pressions

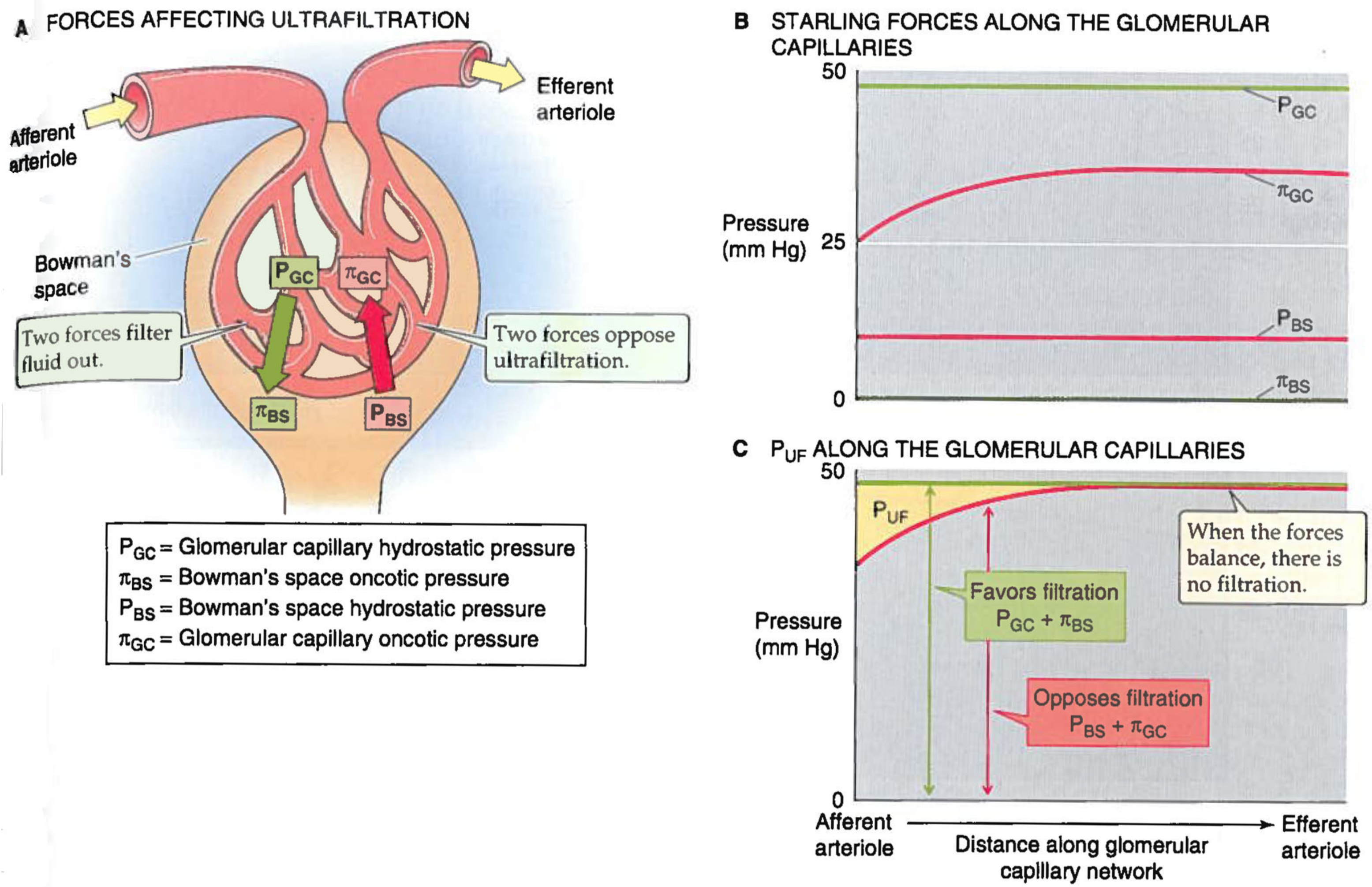
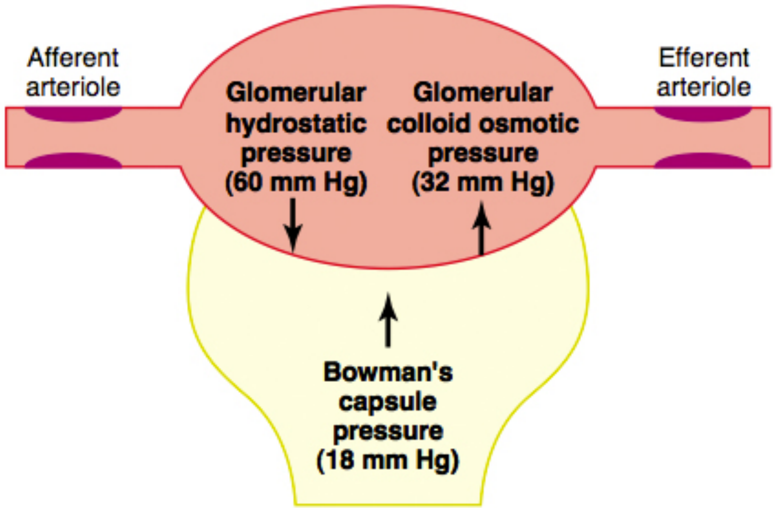


FIGURE 33–5. Glomerular ultrafiltration. In B, the oncotic pressure of the glomerular capillary (π_{GC}), which starts off at the value of normal arterial blood, rises as ultrafiltration removes fluid from the capillary. In C, P_{UF} is the net driving force favoring ultrafiltration.

Système urinaire Déterminants du GFR rôles des 4 pressions

The GFR is determined by:



Net filtration pressure (10 mm Hg) = Glomerular hydrostatic pressure (60 mm Hg) – Bowman's capsule pressure (18 mm Hg) – Glomerular oncotic pressure (32 mm Hg)

Figure 26–12

Summary of forces causing filtration by the glomerular capillaries. The values shown are estimates for healthy humans.

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a) the sum of the *hydrostatic and colloid osmotic forces across the glomerular membrane*, which gives: the ***net filtration pressure***

b) the glomerular capillary filtration coefficient, K_f

$$GFR = K_f \times \text{Net filtration pressure}$$

$$GFR = K_f \times (P_G - P_B - \pi_G + \pi_B)$$

Forces Favoring Filtration (mm Hg)	
Glomerular hydrostatic pressure	60
Bowman's capsule colloid osmotic pressure	0
Forces Opposing Filtration (mm Hg)	
Bowman's capsule hydrostatic pressure	18
Glomerular capillary colloid osmotic pressure	32

Net filtration pressure = 60 – 18 – 32 = +10 mm Hg

P_G = Hydrostatic pressure in glomerular capillary
P_B = Hydrostatic pressure in Bowman's capsule
π_G = Colloid-osmotic pressure in glomerular capillary
π_B = Colloid-osmotic pressure in Bowman's capsule

Système urinaire Déterminants du GFR: rôle de la taille et la charge des molécules

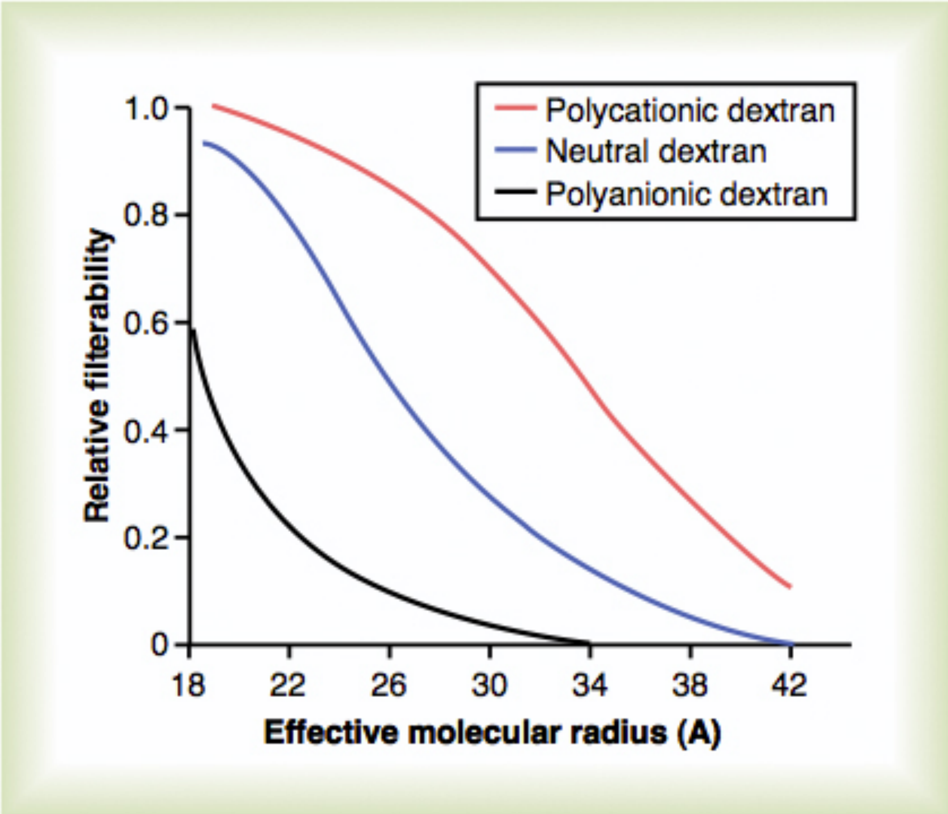
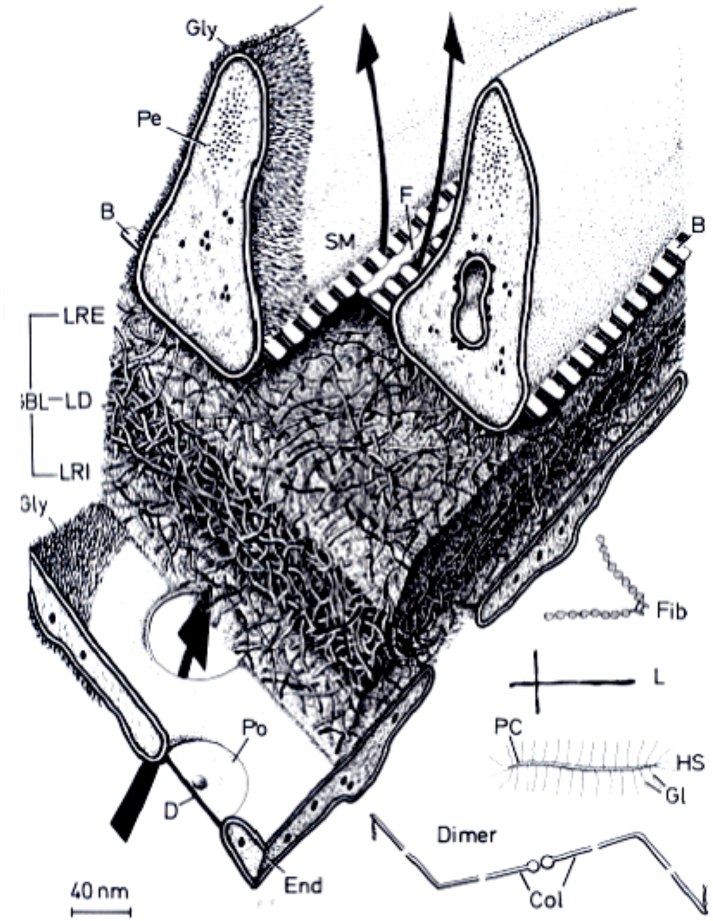
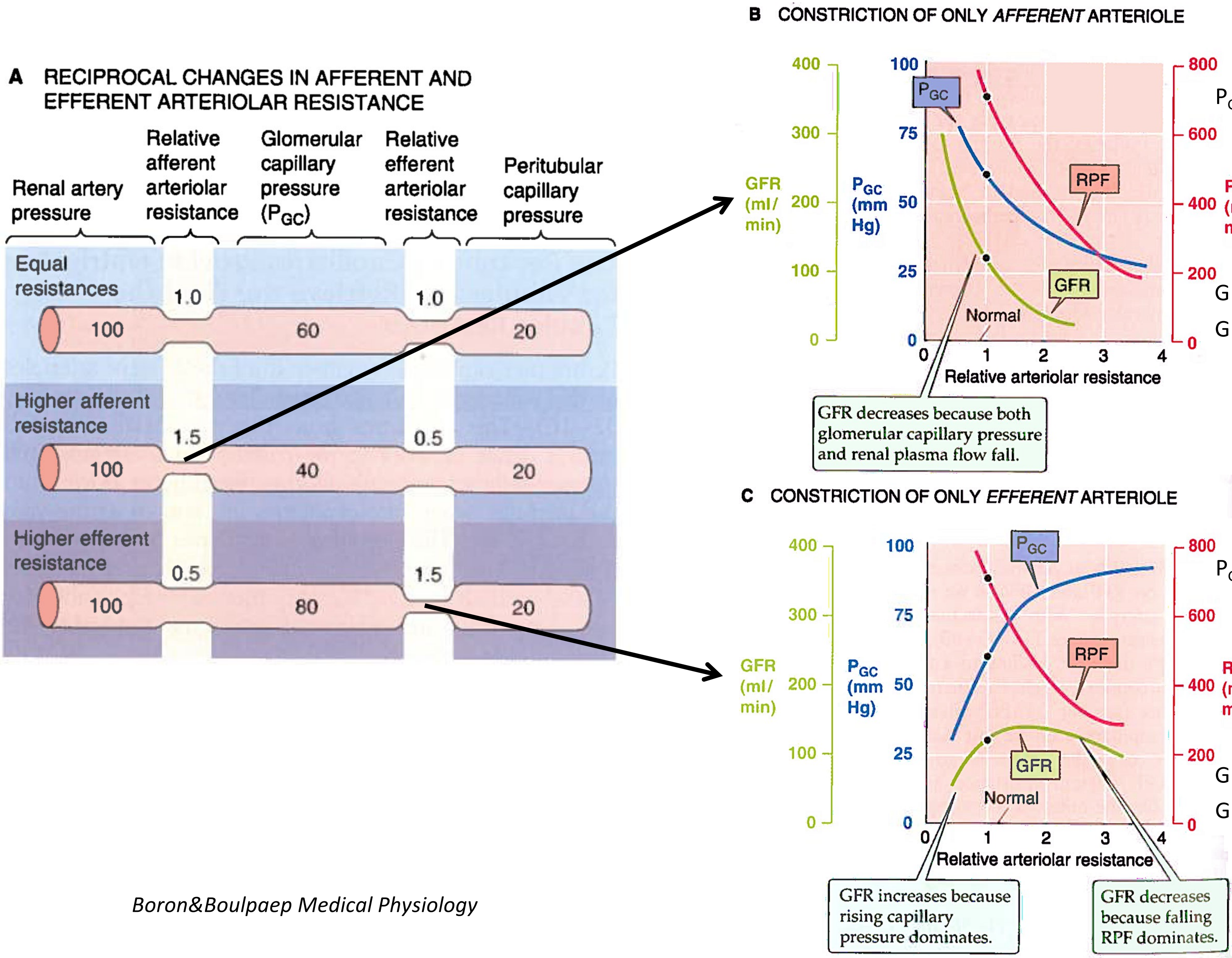


Figure 26–11

Effect of size and electrical charge of dextran on its filterability by the glomerular capillaries. A value of 1.0 indicates that the substance is filtered as freely as water, whereas a value of 0 indicates that it is not filtered. Dextrans are polysaccharides that can be manufactured as neutral molecules or with negative or positive charges and with varying molecular weights.



Système urinaire Déterminants du GFR: rôle des résistances artériolaires



$P_{GC}\downarrow = RPF\downarrow \cdot R_{glo}$

$GFR\downarrow = K_f \cdot (P_{GC}\downarrow - P_{BS} - \pi_{GC})$

$GFR\downarrow = \text{Frac filtr} \cdot RPF\downarrow$

$P_{GC} = RPF\downarrow \cdot R_{art}\uparrow$

$GFR\uparrow = K_f \cdot (P_{GC}\uparrow - P_{BS} - \pi_{GC})$

$GFR\downarrow = \text{Frac filtr} \cdot RPF\downarrow$

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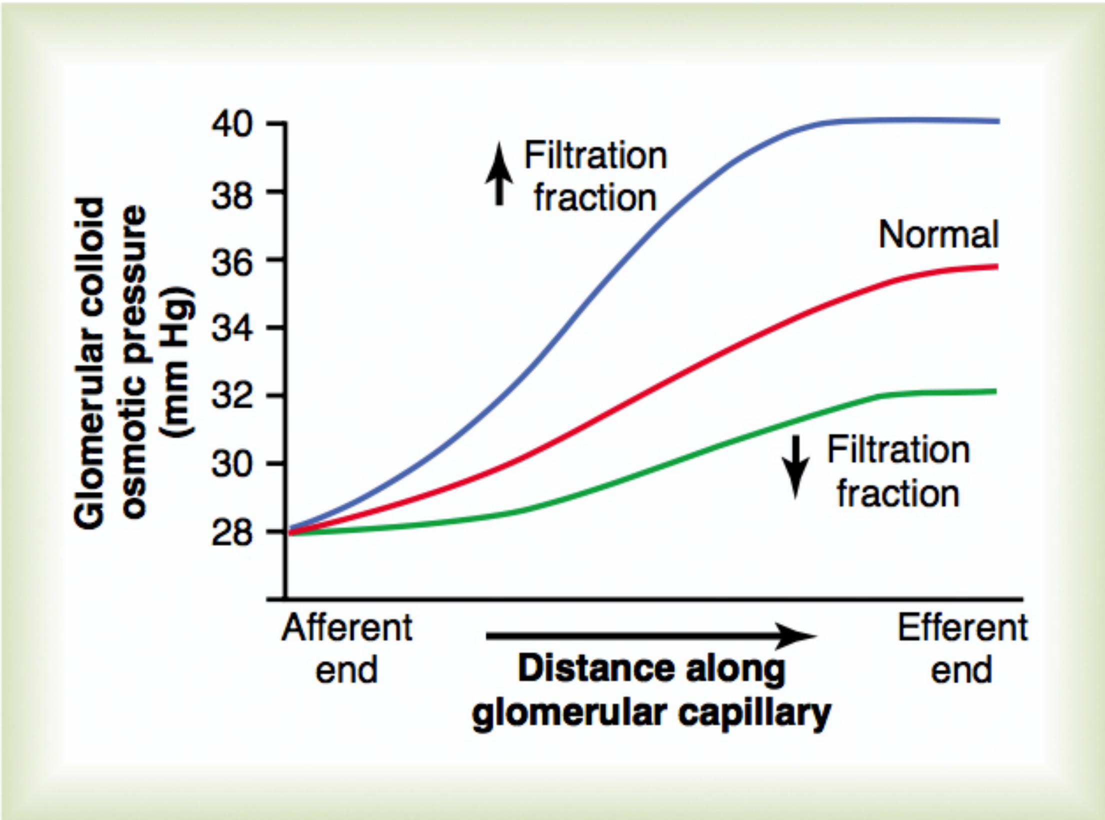
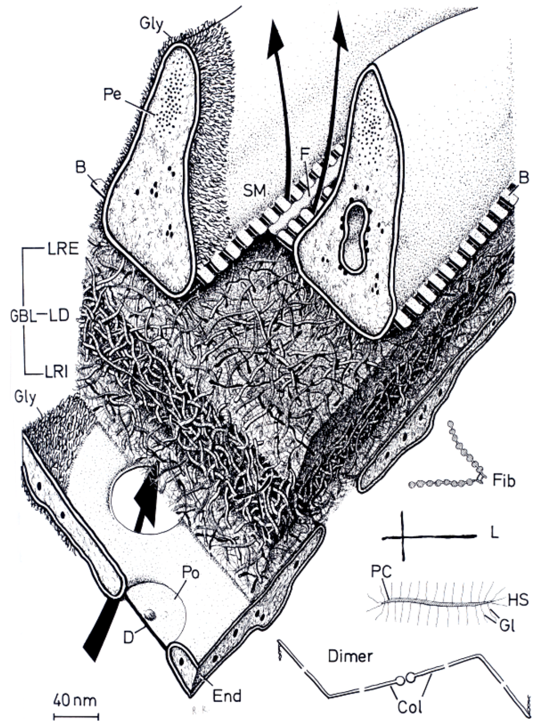
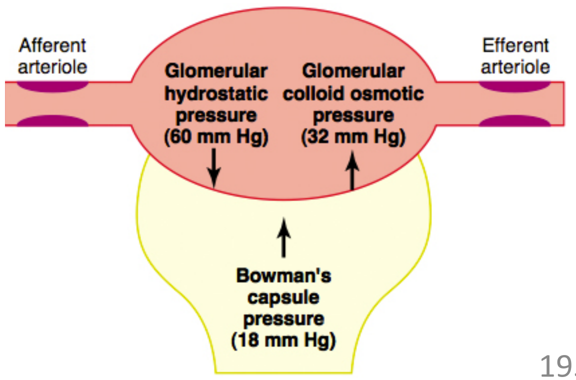
Système urinaire Déterminants du GFR: rôle de la pression osmotique colloïdale

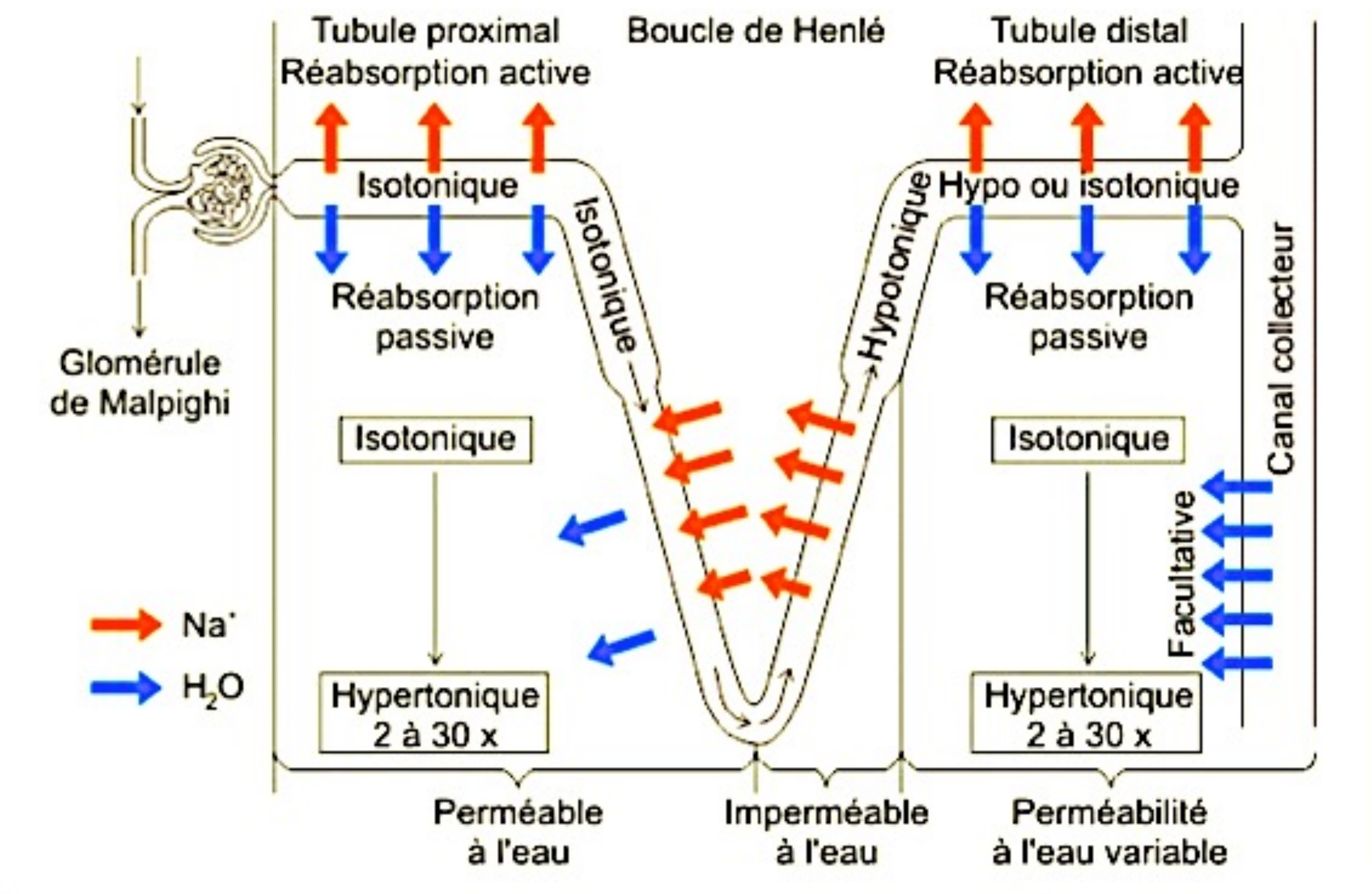


Increase in colloid osmotic pressure in plasma flowing through the glomerular capillary. Normally, about ***one fifth of the fluid in the glomerular capillaries filters into Bowman's capsule***, thereby concentrating the plasma proteins that are not filtered. Increases in the filtration fraction (glomerular filtration rate/renal plasma flow) increase the rate at which the plasma colloid osmotic pressure rises along the glomerular capillary; decreases in the filtration fraction have the opposite effect.





Système urinaire Fonction du néphron: réabsorption Na^+ et H_2O
Circulation des ions et de l'H_2O



Système urinaire Processus tubulaire du filtrat glomérulaire
Rôle des cellules tubulaires

Tubular reabsorption Is selective and quantitatively large

Tubular reabsorption includes passive and active mechanisms

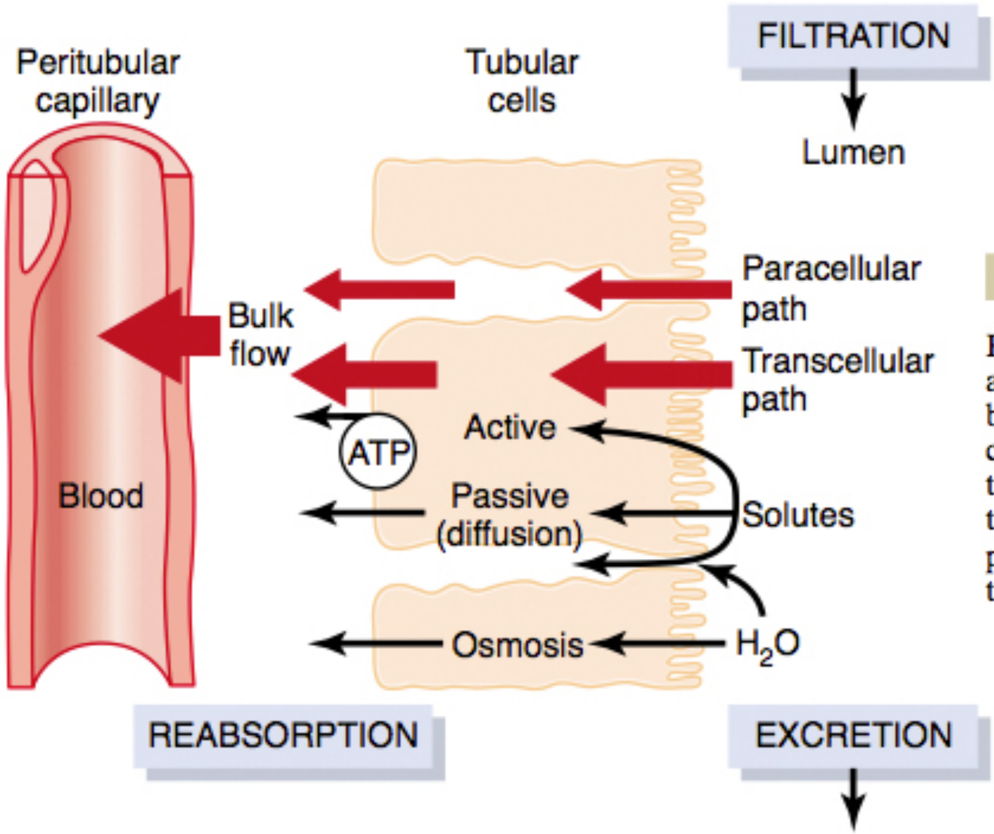


Figure 27–1

Reabsorption of filtered water and solutes from the tubular lumen across the tubular epithelial cells, through the renal interstitium, and back into the blood. Solutes are transported through the cells (transcellular route) by passive diffusion or active transport, or between the cells (paracellular route) by diffusion. Water is transported through the cells and between the tubular cells by osmosis. Transport of water and solutes from the interstitial fluid into the peritubular capillaries occurs by ultrafiltration (bulk flow).

Système urinaire Processus tubulaire du filtrat glomérulaire
Rôle du transport actif

Active Transport

- Solutes can be transported *through* epithelial cells or *between* cells
- Primary active transport *through* the tubular membrane is linked to **hydrolysis of ATP**
- Secondary active reabsorption through the tubular membrane
- Secondary active secretion into the tubules
- Pinocytosis: an active transport mechanism for the reabsorption of proteins

Transport is maximum for substances that are actively reabsorbed

Système urinaire Processus tubulaire du filtrat glomérulaire types de transport

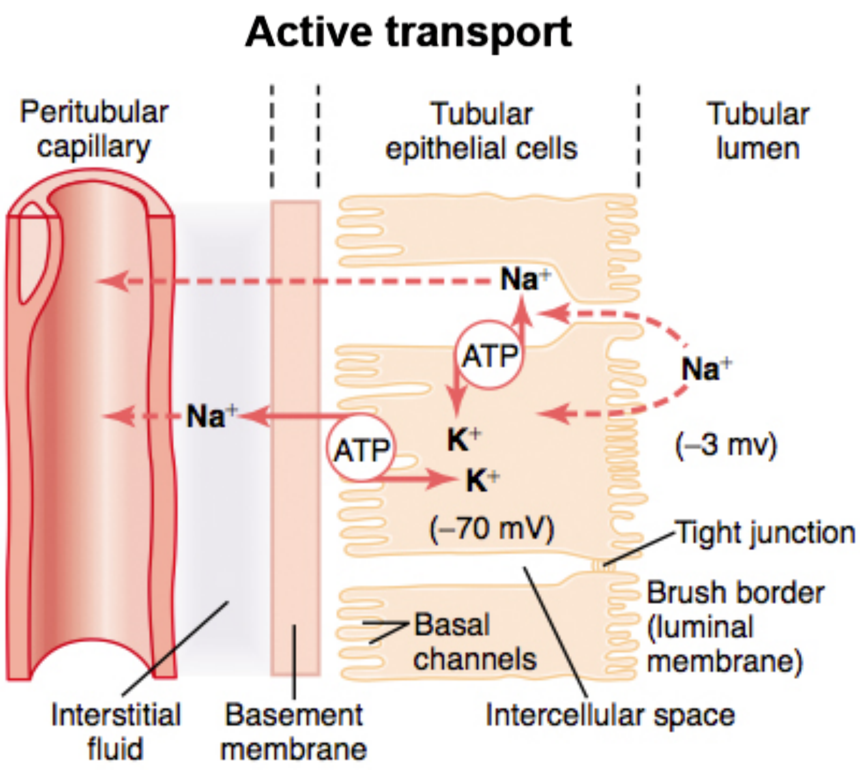


Figure 27–2

Basic mechanism for active transport of sodium through the tubular epithelial cell. The sodium-potassium pump transports sodium from the interior of the cell across the basolateral membrane, creating a low intracellular sodium concentration and a negative intracellular electrical potential. The low intracellular sodium concentration and the negative electrical potential cause sodium ions to diffuse from the tubular lumen into the cell through the brush border.

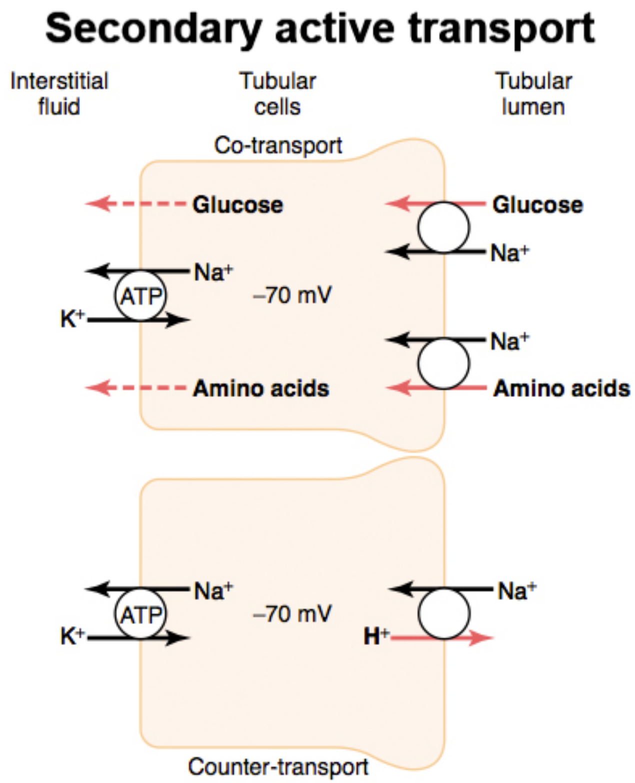


Figure 27–3

Mechanisms of secondary active transport. The upper cell shows the *co-transport* of glucose and amino acids along with sodium ions through the apical side of the tubular epithelial cells, followed by facilitated diffusion through the basolateral membranes. The lower cell shows the *counter-transport* of hydrogen ions from the interior of the cell across the apical membrane and into the tubular lumen; movement of sodium ions into the cell, down an electrochemical gradient established by the sodium-potassium pump on the basolateral membrane, provides the energy for transport of the hydrogen ions from inside the cell into the tubular lumen.

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Système urinaire Exemple de réabsorption tubulaire proximale

water

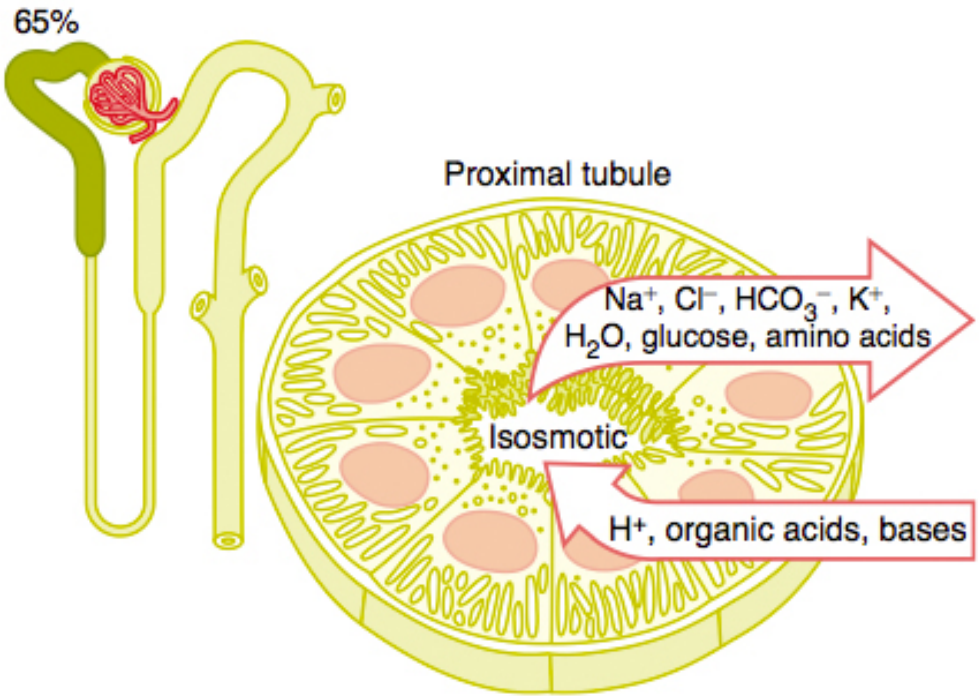
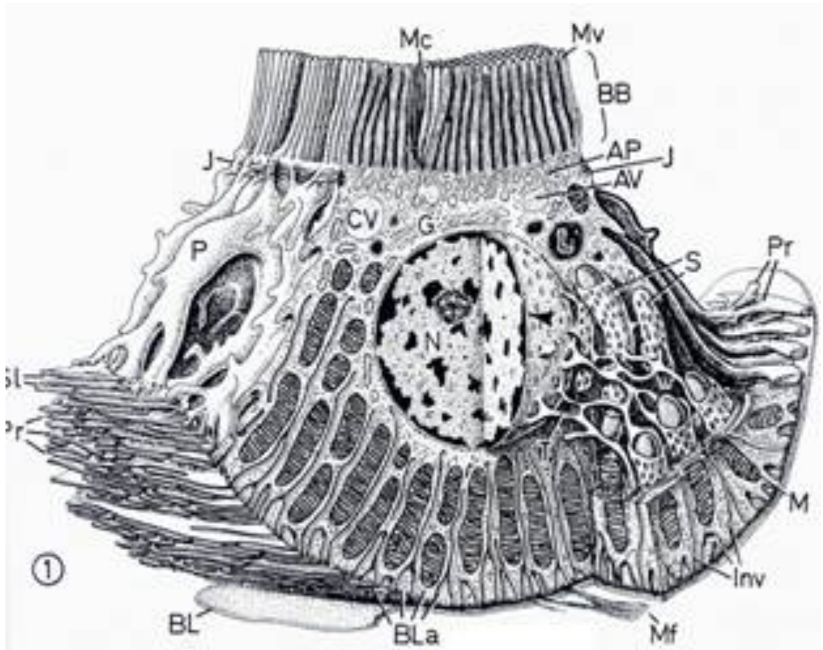


Figure 27–6

Cellular ultrastructure and primary transport characteristics of the proximal tubule. The proximal tubules reabsorb about 65 per cent of the filtered sodium, chloride, bicarbonate, and potassium and essentially all the filtered glucose and amino acids. The proximal tubules also secrete organic acids, bases, and hydrogen ions into the tubular lumen.



Système urinaire Nature de la réabsorption tubulaire proximale

↑ Filtré/Sécrété

↓ Réabsorbé

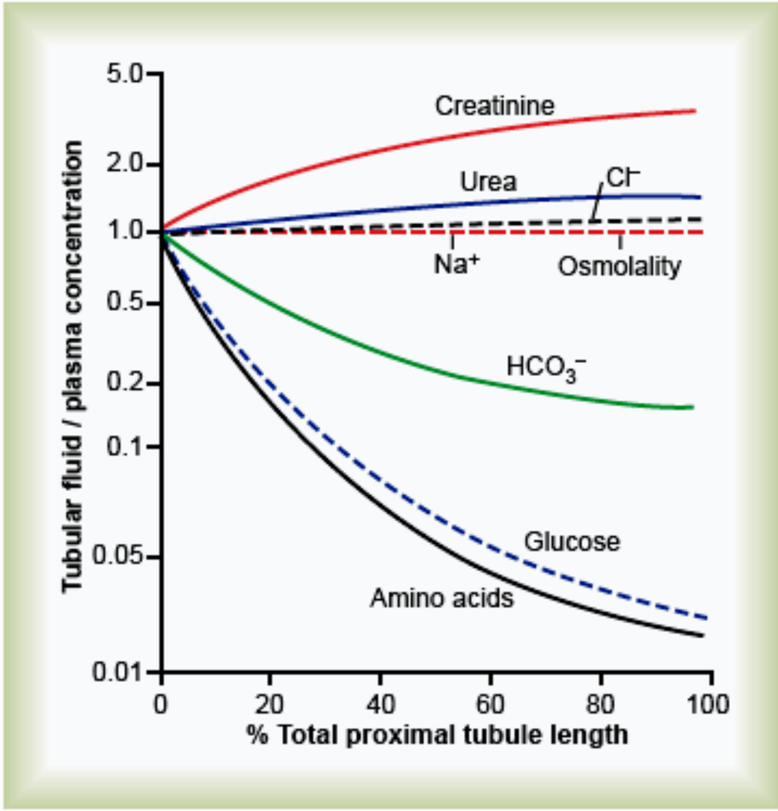
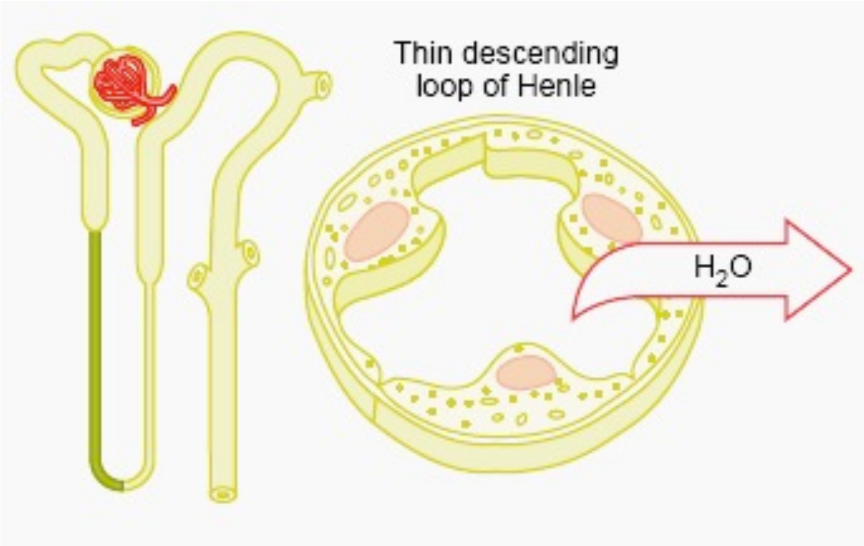


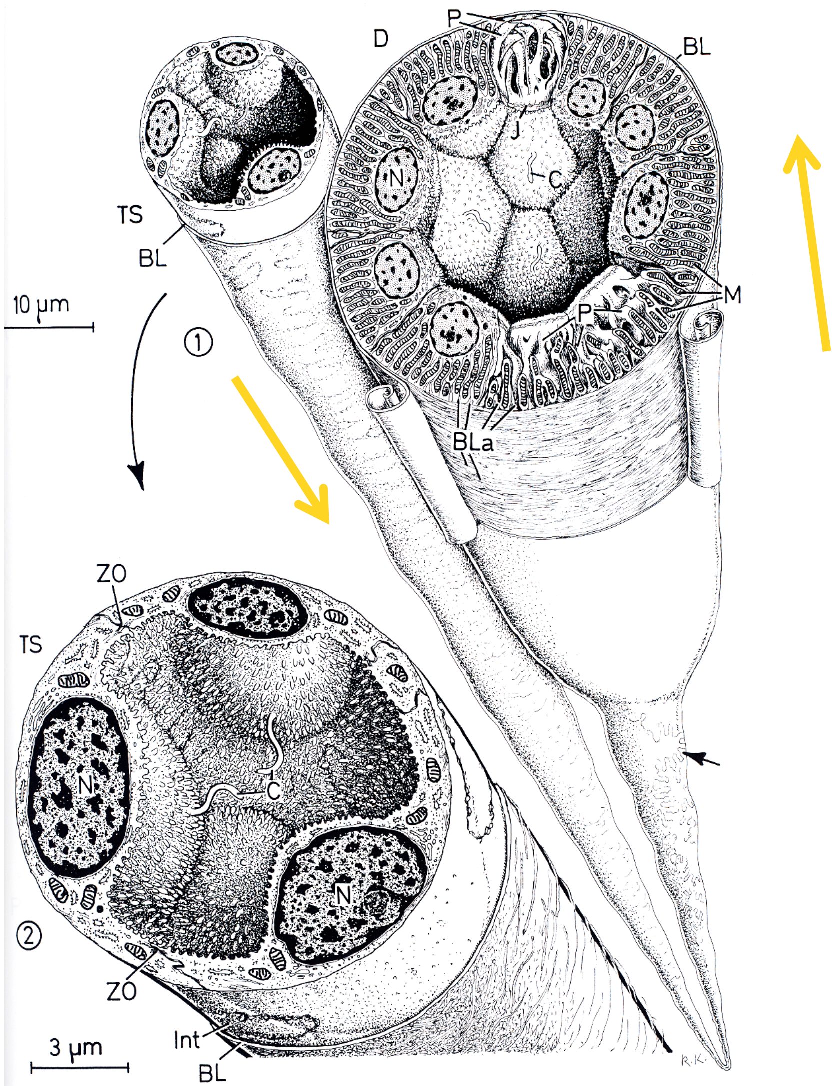
Figure 27–7

Changes in concentrations of different substances in tubular fluid along the proximal convoluted tubule relative to the concentrations of these substances in the plasma and in the glomerular filtrate. A value of 1.0 indicates that the concentration of the substance in the tubular fluid is the same as the concentration in the plasma. Values below 1.0 indicate that the substance is reabsorbed more avidly than water, whereas values above 1.0 indicate that the substance is reabsorbed to a lesser extent than water or is secreted into the tubules.

- Les tubules proximaux ont une grande capacité de réabsorption active et passive => H_2O suit
- Concentrations de solutés le long du tubule proximal.
- Sécrétion d'acides organiques et de bases par le tubule proximal.
- *L'eau et le Na^+ sont réabsorbés sous une forme isosmotique!*

Système urinaire Rôle de l'anse fine de Henle dans le transport de solutés et H_2O



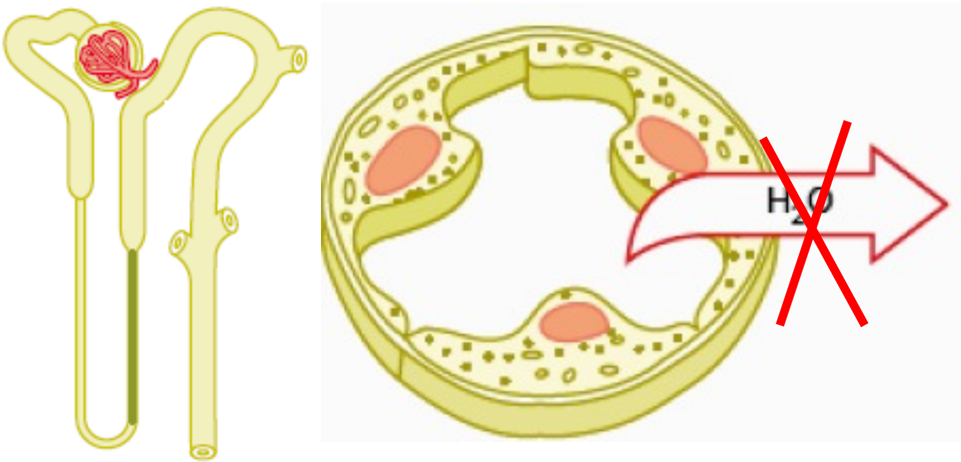


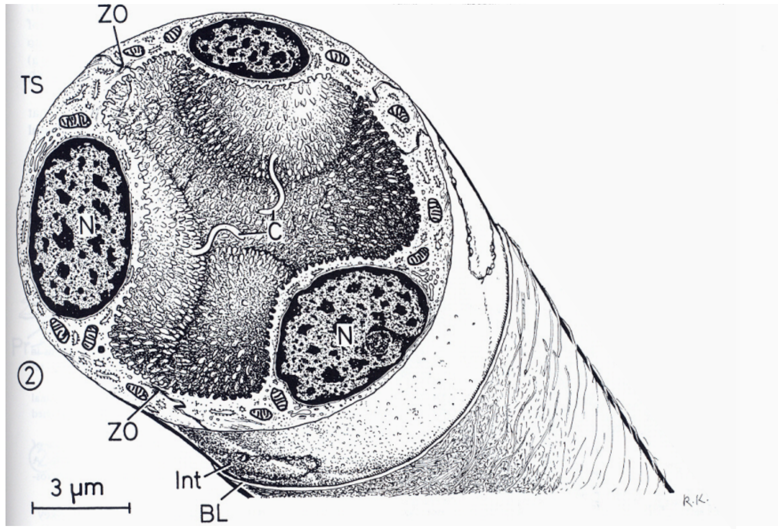
L'anse de Henle est constituée de trois segments fonctionellement distincts : *le segment fin descendant*, *le segment fin ascendant*, *et le segment large ascendant.*

Les segments fin descendant et fin ascendant, comme leurs noms l'indiquent, ont une fine membrane épithéliale sans bordure en brosse, peu de mitochondries, et un niveau minimal d'activité métabolique.

Le segment fin descendant est hautement perméable à l'eau et modérément perméable à la plupart des solutés, y compris l'urée et le sodium. La fonction de ce segment du néphron est principalement de permettre la simple diffusion de substances au travers de sa paroi.

Système urinaire Transport de solutés et H_2O dans l'anse fine de Henle
Imperméabilité à l'H_2O



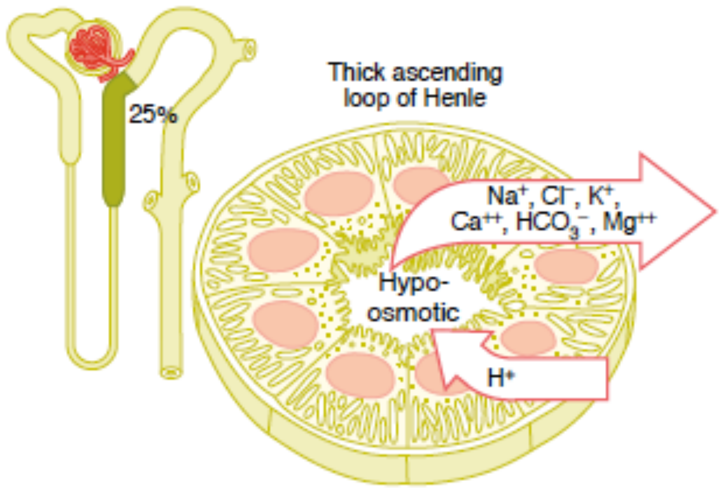


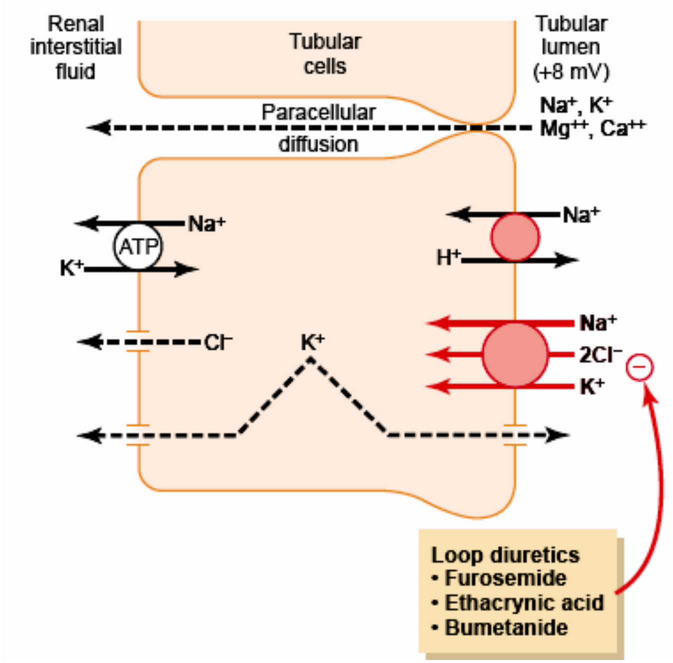
La branche ascendante, incluant à la fois la portion fine et large, **est virtuellement imperméable à l'eau**, une charactéristique qui est importante pour concentrer l'urine. Le segment fin de la branche ascendante a une plus faible capacité de réabsorption que le segment large de la branche ascendante.

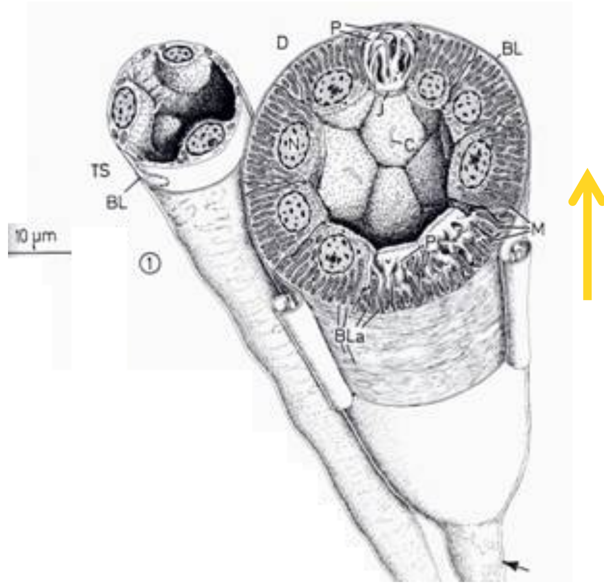
Dans la boucle ascendante de Henle l'H_2O ne diffuse pas hors du lumen dans l'interstitium rénal.

Seul le Na^+ diffuse hors du lumen dans l'interstitium rénal par l'effet du gradient hyperosmotique.

Système urinaire Rôle de l’anse large de Henle dans le transport de solutés

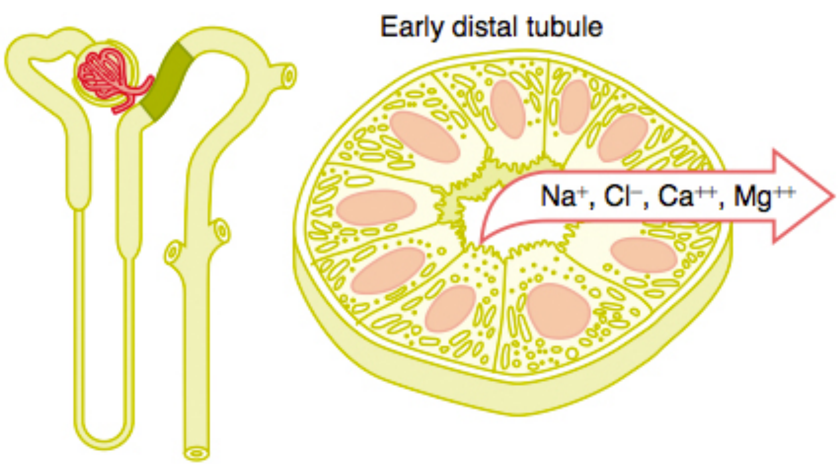


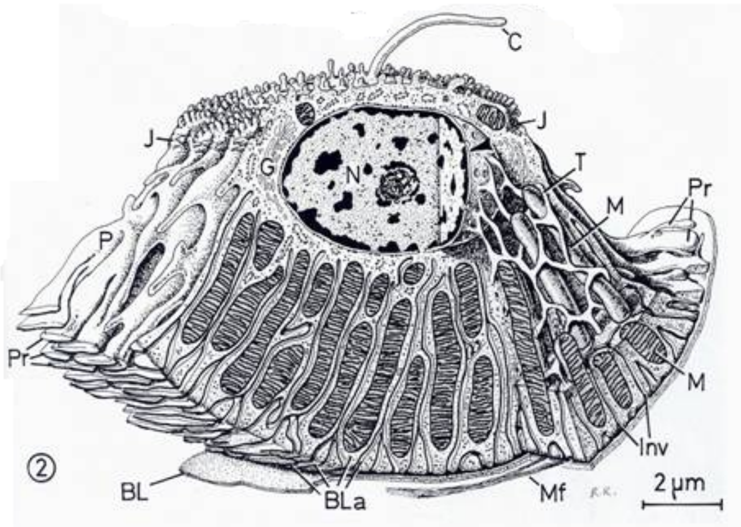




L’anse large de Henle, qui commence à la moitié de la branche ascendante, est constituée de cellules épithéliales épaisses qui ont une forte activité métabolique et qui **sont capables de réabsorption active de sodium, chlore, et potassium.** Environ 25 pour cent de la charge filtrée en sodium, chlore, et potassium sont réabsorbés dans l’anse de Henle, principalement dans la branche large ascendante. Une quantité considérable d’autres ions, tels que le calcium, le bicarbonate, et le magnesium, est également réabsorbée dans l’anse large de Henle.

Système urinaire Rôle du tube contourné distal dans le transport de solutés





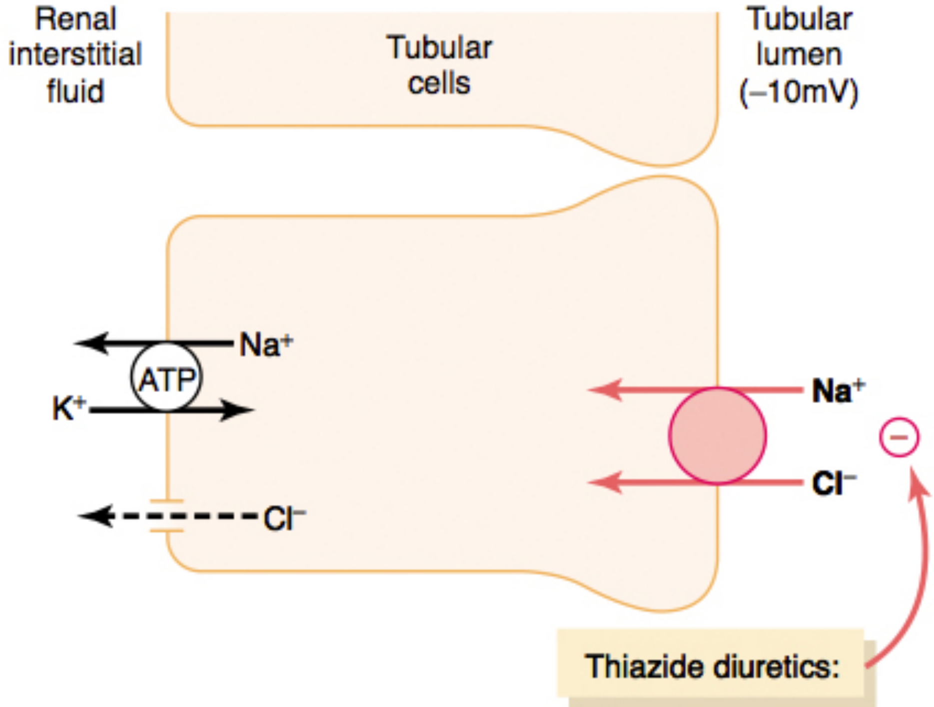


Figure 27–10

Mechanism of sodium chloride transport in the early distal tubule. Sodium and chloride are transported from the tubular lumen into the cell by a co-transporter that is inhibited by thiazide diuretics. Sodium is pumped out of the cell by sodium-potassium ATPase and chloride diffuses into the interstitial fluid via chloride channels.

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Système urinaire Rôle du tube distal et collecteur cortical dans le transport de solutés

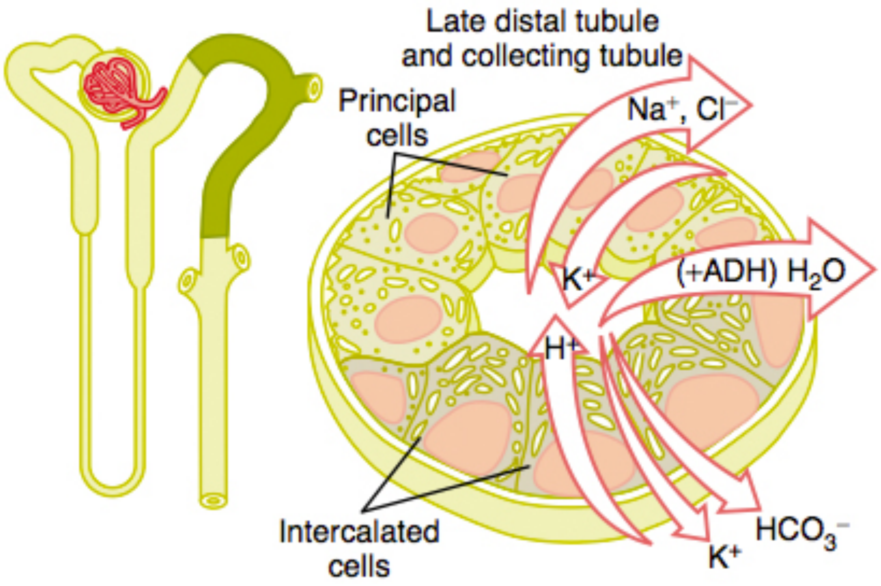

Figure 27–11

Cellular ultrastructure and transport characteristics of the early distal tubule and the late distal tubule and collecting tubule. The early distal tubule has many of the same characteristics as the thick ascending loop of Henle and reabsorbs sodium, chloride, calcium, and magnesium but is virtually impermeable to water and urea. The late distal tubules and cortical collecting tubules are composed of two distinct cell types, the *principal cells* and the *intercalated cells*. The principal cells reabsorb sodium from the lumen and secrete potassium ions into the lumen. The intercalated cells reabsorb potassium and bicarbonate ions from the lumen and secrete hydrogen ions into the lumen. The reabsorption of water from this tubular segment is controlled by the concentration of *antidiuretic hormone*.

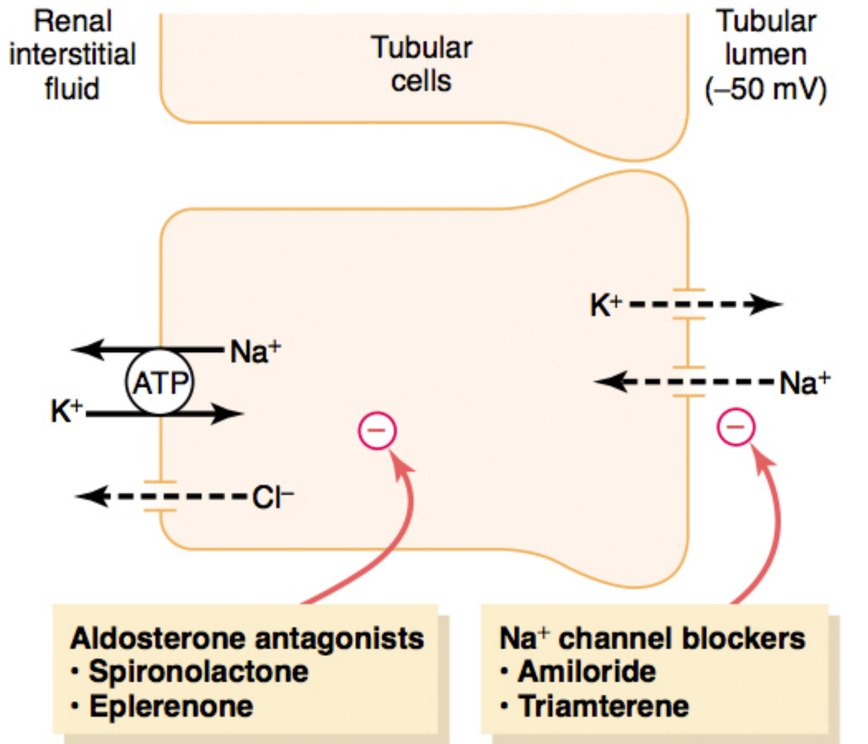

Figure 27–12

Mechanism of sodium chloride reabsorption and potassium secretion in the late distal tubules and cortical collecting tubules. Sodium enters the cell through special channels and is transported out of the cell by the sodium-potassium ATPase pump. Aldosterone antagonists compete with aldosterone for binding sites in the cell and therefore inhibit the effects of aldosterone to stimulate sodium reabsorption and potassium secretion. Sodium channel blockers directly inhibit the entry of sodium into the sodium channels.

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Système urinaire Rôle du tube collecteur médullaire dans le transport de solutés
Importance de la réabsorption de l'H_2O

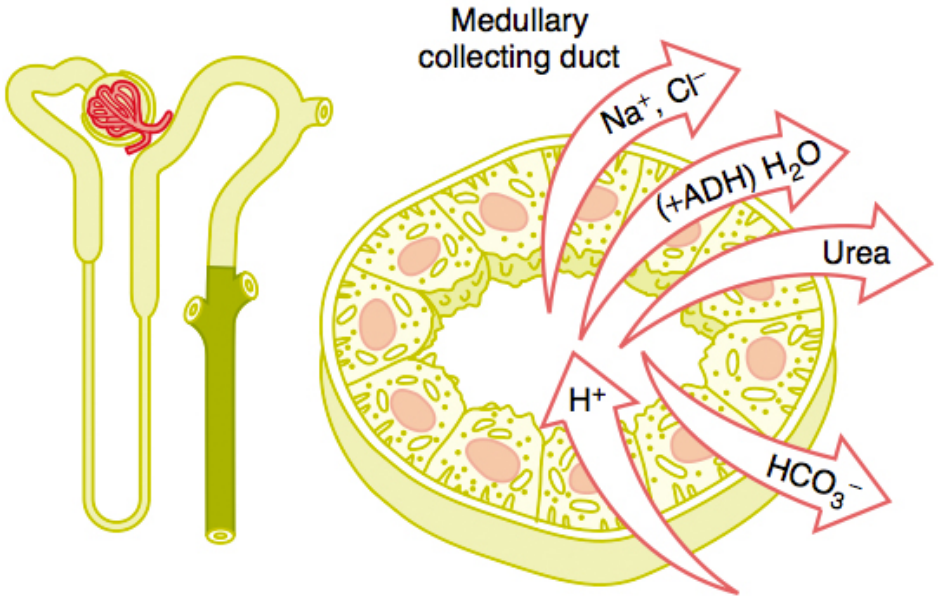
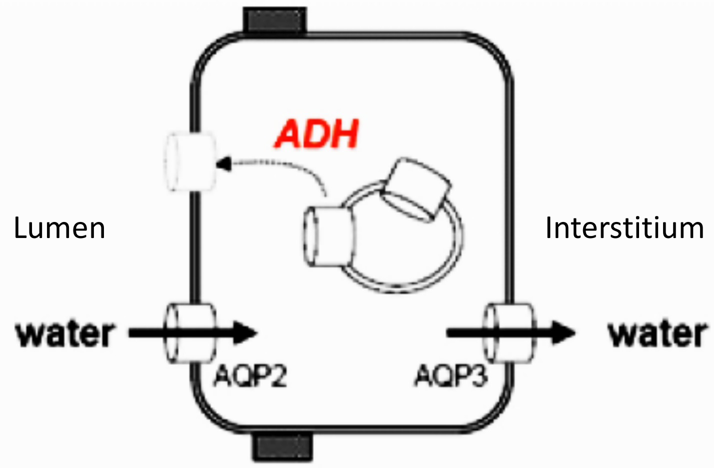


Figure 27–13

Cellular ultrastructure and transport characteristics of the medullary collecting duct. The medullary collecting ducts actively reabsorb sodium and secrete hydrogen ions and are permeable to urea, which is reabsorbed in these tubular segments. The reabsorption of water in medullary collecting ducts is controlled by the concentration of antidiuretic hormone.



Aquaporine-2 Aquaporine-3

Système urinaire Métabolisme oxidatif rénal et réabsorption de Na^+

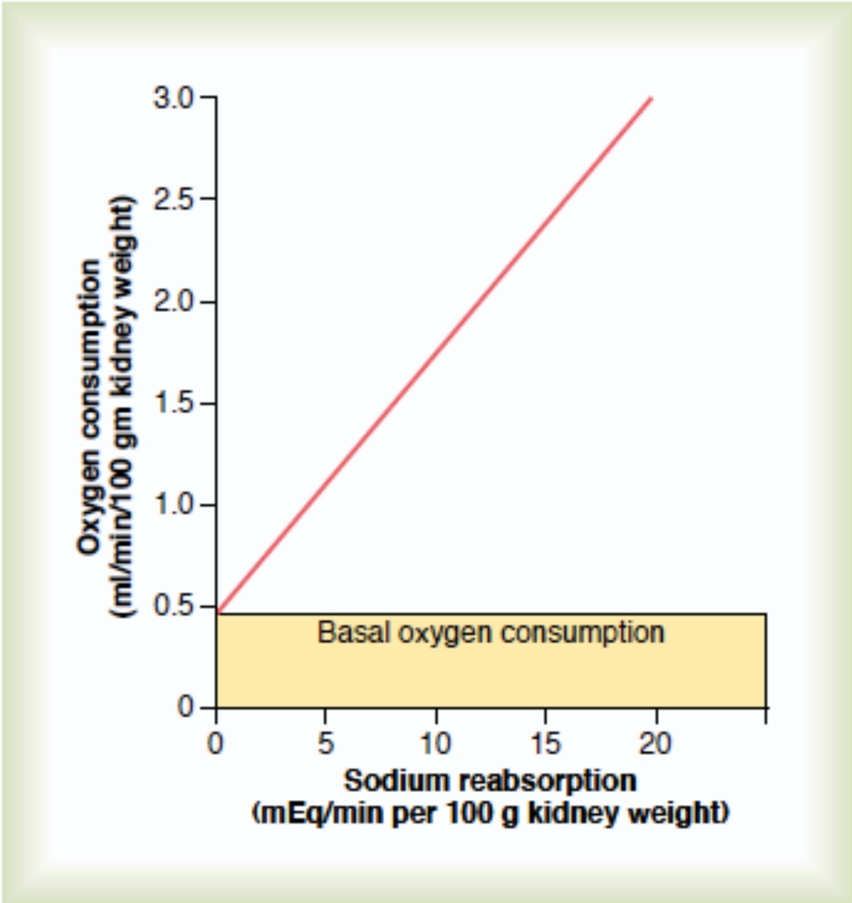


Figure 26–15

Relationship between oxygen consumption and sodium reabsorption in dog kidneys. (Kramer K, Deetjen P: Relation of renal oxygen consumption to blood supply and glomerular filtration during variations of blood pressure. Pflugers Arch Physiol 271:782, 1960.)

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Système urinaire Exemple du glucose

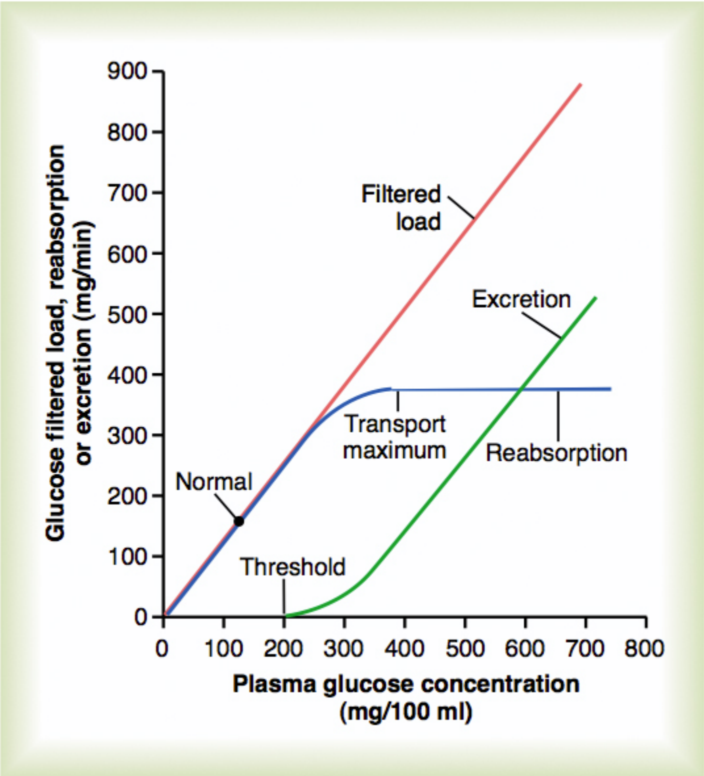


Figure 27–4

Relations among the filtered load of glucose, the rate of glucose reabsorption by the renal tubules, and the rate of glucose excretion in the urine. The *transport maximum* is the maximum rate at which glucose can be reabsorbed from the tubules. The *threshold* for glucose refers to the filtered load of glucose at which glucose first begins to be excreted in the urine.

Reabsorption

Substance	Transport Maximum
Glucose	375 mg/min
Phosphate	0.10 mM/min
Sulfate	0.06 mM/min
Amino acids	1.5 mM/min
Urate	15 mg/min
Lactate	75 mg/min
Plasma protein	30 mg/min

Secretion in the tubular lumen

Substance	Transport Maximum
Creatinine	16 mg/min
Para-aminohippuric acid	80 mg/min

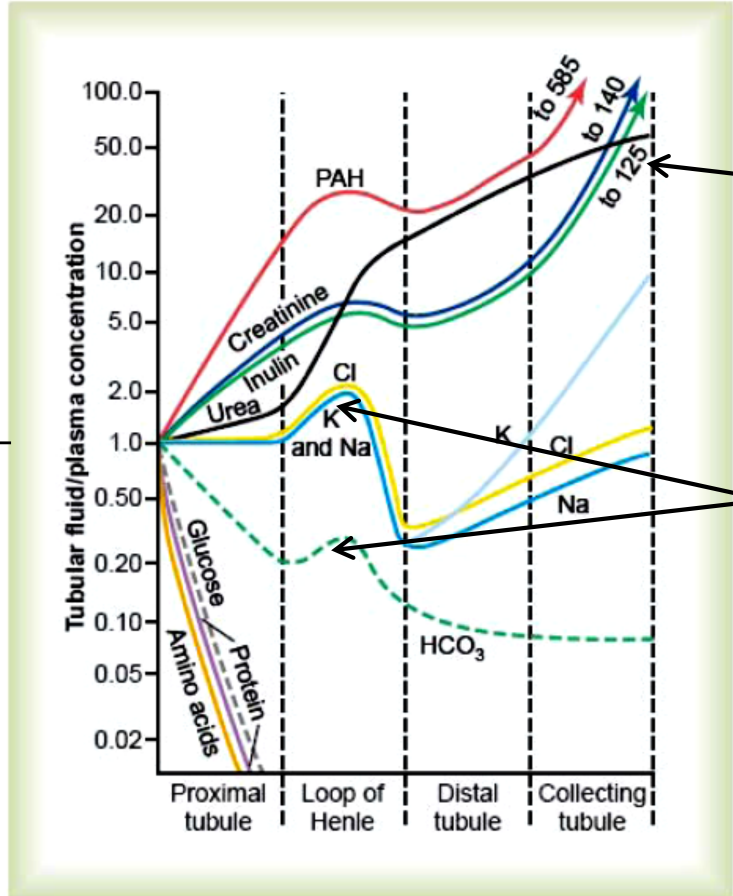
Guyton et Hall Medical Physiology 209

Système urinaire Résumé de la fonction rénale (néphron juxtamédullaire)

Filtré/Sécrété

Summary of urine processing by the nephron

Réabsorbé



Démontre l'effet de réabsorption de l'eau et la concentration des solutés dans le tube collecteur

Démontre l'effet de réabsorption de l'eau et la concentration des solutés dans l'anse fine descendante de Henle

Figure 27–14

Changes in average concentrations of different substances at different points in the tubular system relative to the concentration of that substance in the plasma and in the glomerular filtrate. A value of 1.0 indicates that the concentration of the substance in the tubular fluid is the same as the concentration of that substance in the plasma. Values below 1.0 indicate that the substance is reabsorbed more avidly than water, whereas values above 1.0 indicate that the substance is reabsorbed to a lesser extent than water or is secreted into the tubules.

Guyton et Hall Medical Physiology

Système urinaire 2 populations de néphrons: corticaux vs. juxtamédullaires
Importances des 2 types de néphrons pour la fonction rénale

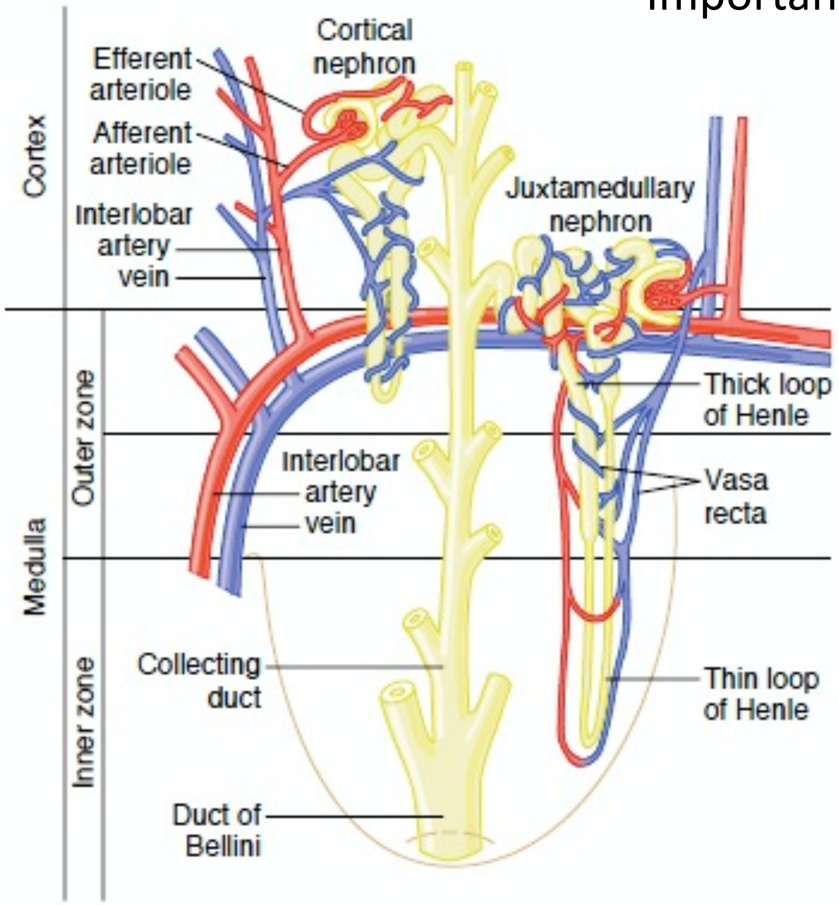
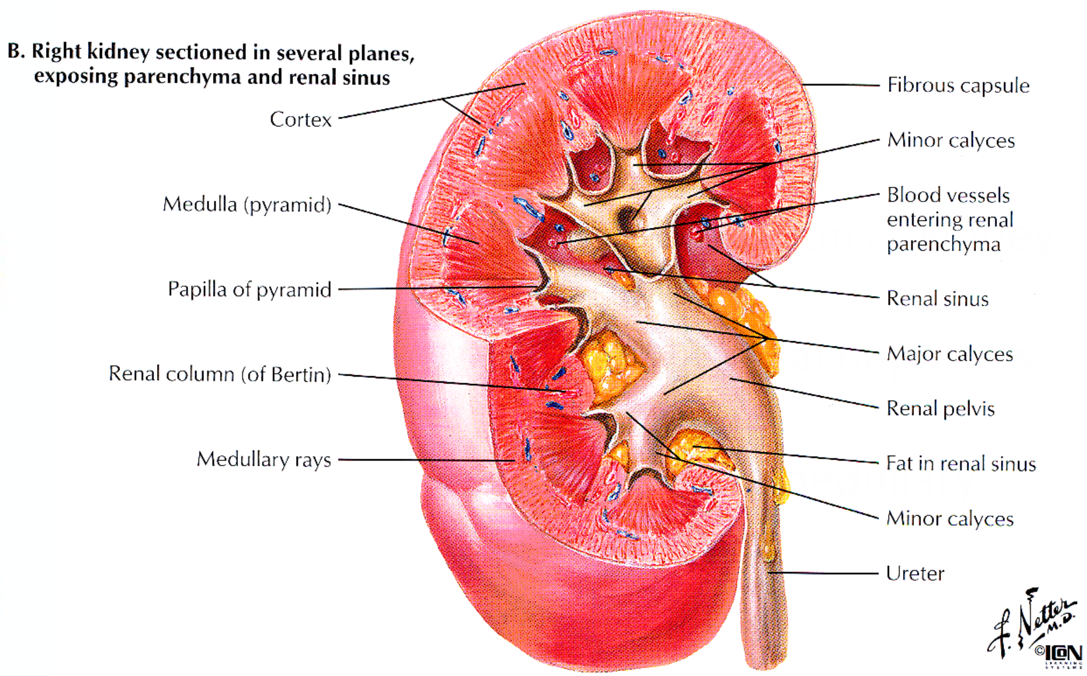


Figure 26–5

Schematic of relations between blood vessels and tubular structures and differences between cortical and juxtamedullary nephrons.



- 1.4×10^6 néphrons / rein
- 85% sont des néphrons corticaux
- 15% sont juxtamédullaires

Nettler Atlas of Anatomy

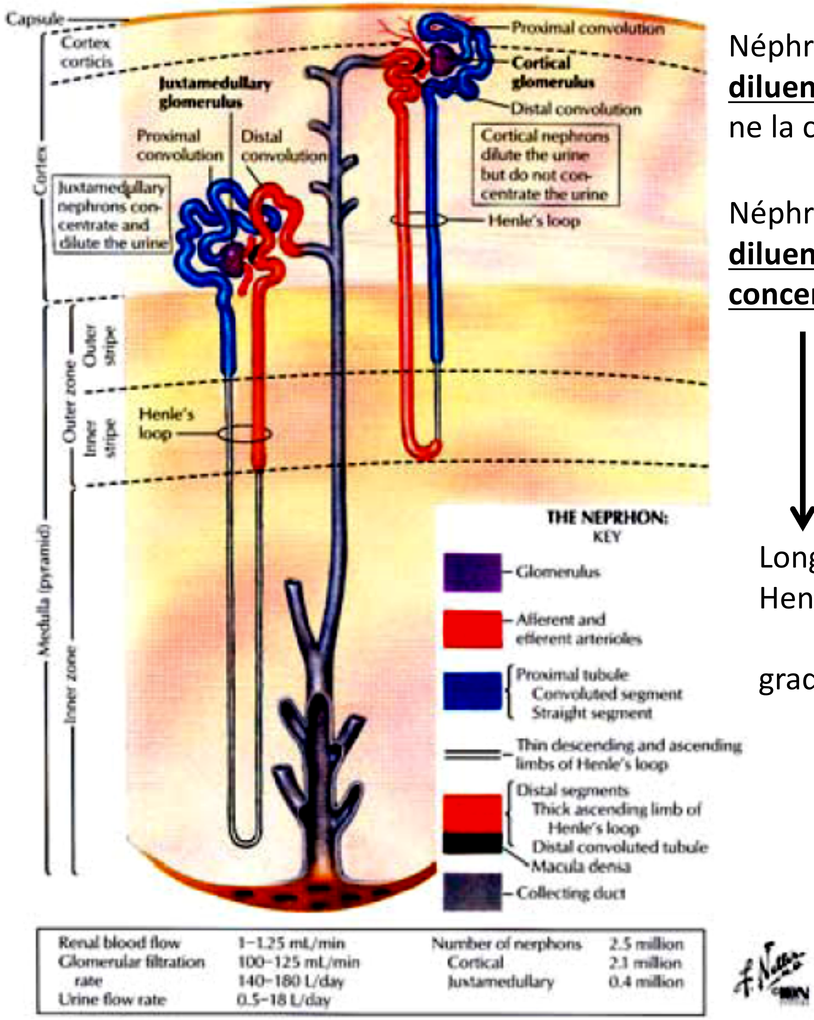
Système urinaire Rôle des 2 types de néphrons corticaux vs. juxtamédullaires

Where ions are pumped to create the medullary hyperosmotic gradient?

Summary of Tubule Characteristics—Urine Concentration

	Active NaCl Transport	Permeability H_2O	Permeability NaCl	Permeability Urea
Proximal tubule	++	++	+	+
Thin descending limb	0	++	+	+
Thin ascending limb	0	0	+	+
Thick ascending limb	++	0	0	0
Distal tubule	+	+ADH	0	0
Cortical collecting tubule	+	+ADH	0	0
Inner medullary collecting duct	+	+ADH	0	++ADH

0, minimal level of active transport or permeability; +, moderate level of active transport or permeability; ++, high level of active transport or permeability; +ADH, permeability to water or urea is increased by ADH.



Néphrons corticaux **diluent** l'urine mais ne la concentrent pas

Néphrons juxtamédullaires **diluent** l'urine et **concentrent** l'urine

↓

Longues anses de Henle médullaires

↓

gradient hyperosmolaire

Nettler Atlas of Anatomy

Système urinaire Résumé des fonctions tubulaires

TUBULAR FUNCTIONS

Proximal tubule Distal tubule Collecting tube	**TRANSEPITHELIAL TRANSPORTS**
	RE-UPTAKE OF FILTERED SUBSTANCES water, Na^+, K^+, Ca^{++}, Cl^-, HCO_3^-, PO_4^{---} glucose, amino acids, proteins...
	SECRETION OF SUBSTANCES TO BE ELIMINATED H^+, K^+, SO_4^{--}, org^+, org^- urea, NH_4^+, creatinine, xenobiotiques....
Henle's loop	**MAINTAINING OF PAPILLARY OSMOTIC GRADIENT** concentration or dilution of the urine
	DIFFERENTIATION ALONG THE NEPHRON

Energetics oxidative phosporylation → O_2 necessary

Recall: **EXCRETION = FILTRATION – REABSORPTION + SECRETION**