# Regulation of fluid and electrolytes balance

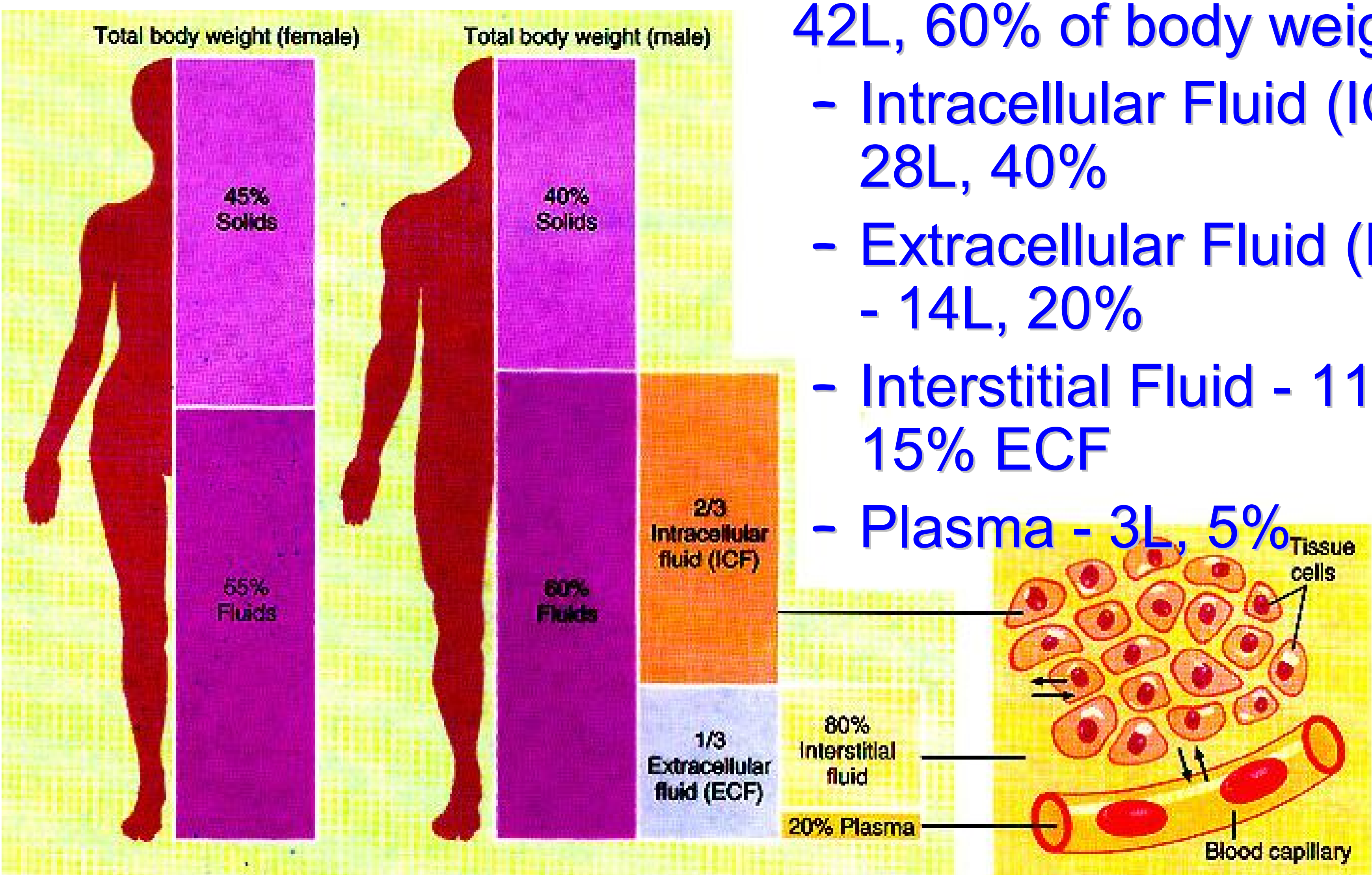
## Fluid Compartments

Three Compartment

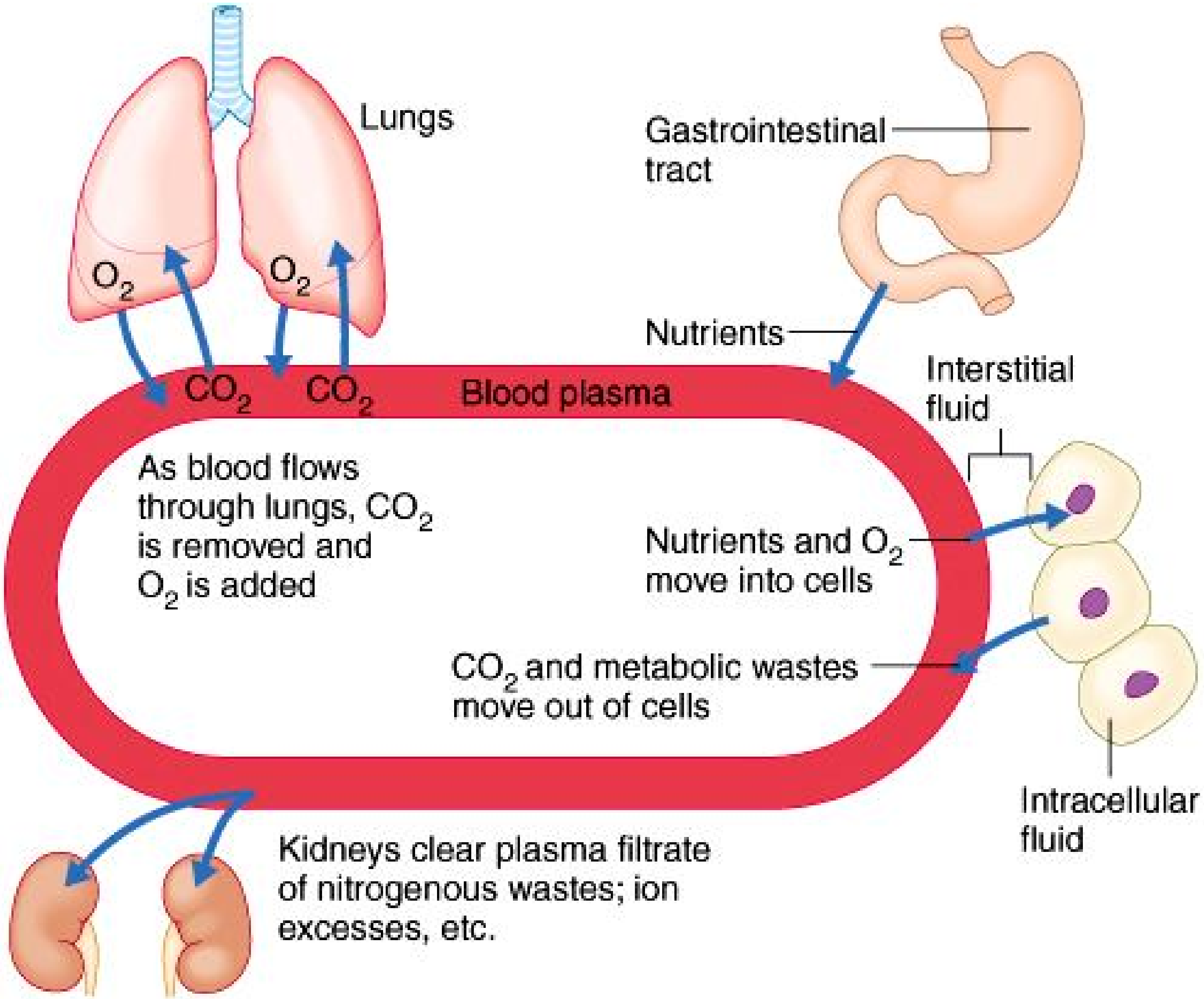
- Intracellular = Cytoplasmic (inside cells)
- Extracellular compartment is subdivided into
- Interstitial = Intercellular + Lymph (between the cells in the tissues)
- Plasma (fluid portion of the blood)

# Fluid Compartments

- Total Body Water (TBW) - 42L, 60% of body weight
  - Intracellular Fluid (ICF) - 28L, 40%
  - Extracellular Fluid (ECF) - 14L, 20%
  - Interstitial Fluid - 11L, 15% ECF
  - Plasma - 3L, 5%



# Regulation of fluid and electrolytes balance



# Effective Circulating Volume (ECV)

- It refers to the portion of ECF volume that is contained within the vascular system and is **effectively perfusing the tissues.**
- It is not a measurable and distinct body fluid compartment. **Defined physiologically and not anatomically.**
- Dependent upon **volume and pressure of the vascular system.**

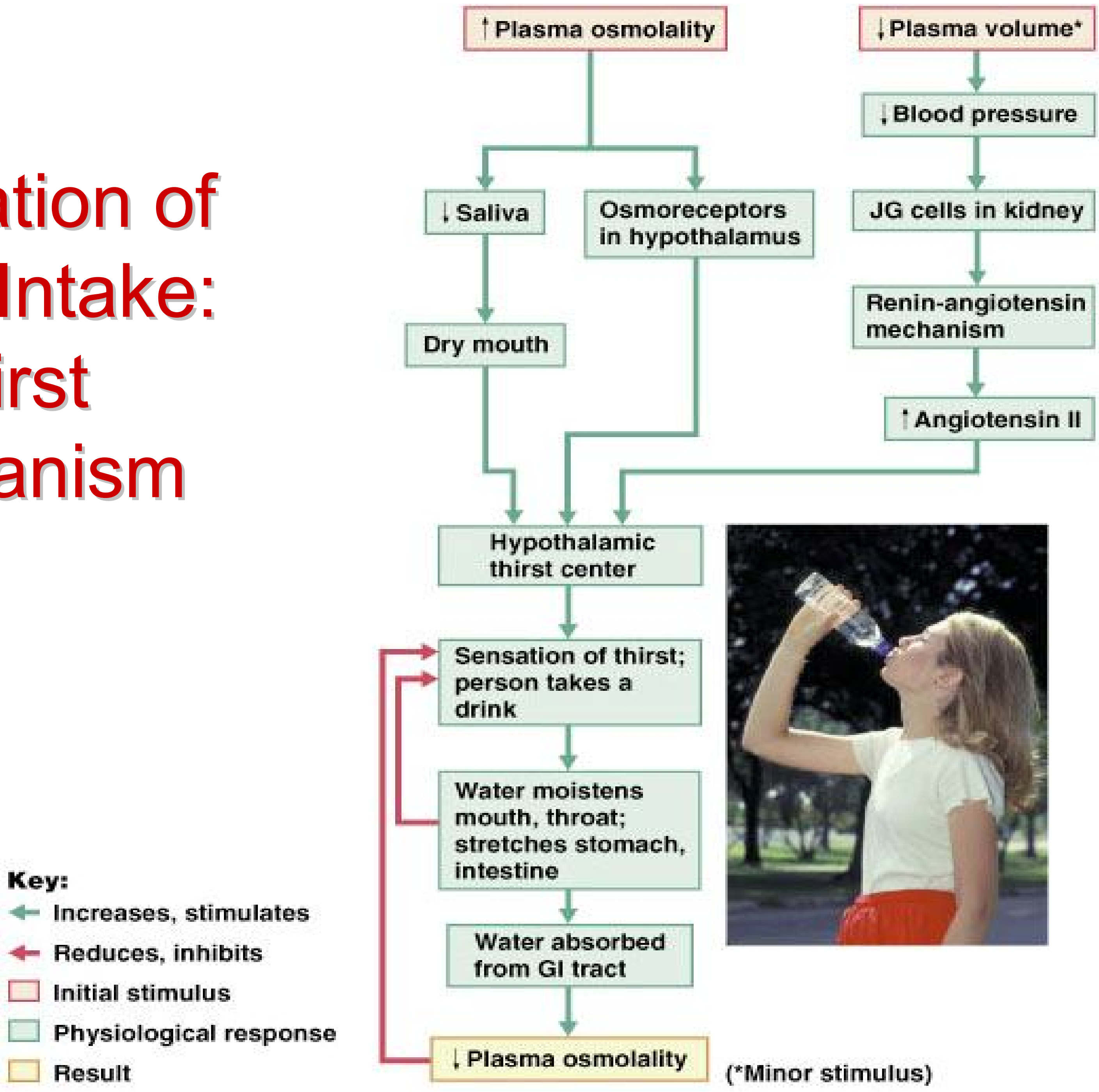
# Effective Circulating Volume (ECV)

- Decrease in volume or pressure will be sensed as decrease in ECV.
- $Na^+$ balance in turn determines volume or pressure. So, kidney alters $Na^+$ excretion in response to ECV.
- In pathology, ECV can vary independently of its determining factors. (ex. in congestive heart failure, the tissue perfusion is poor. Kidneys retain NaCl and water resulting in edema.)

# Water Balance and ECF Osmolality

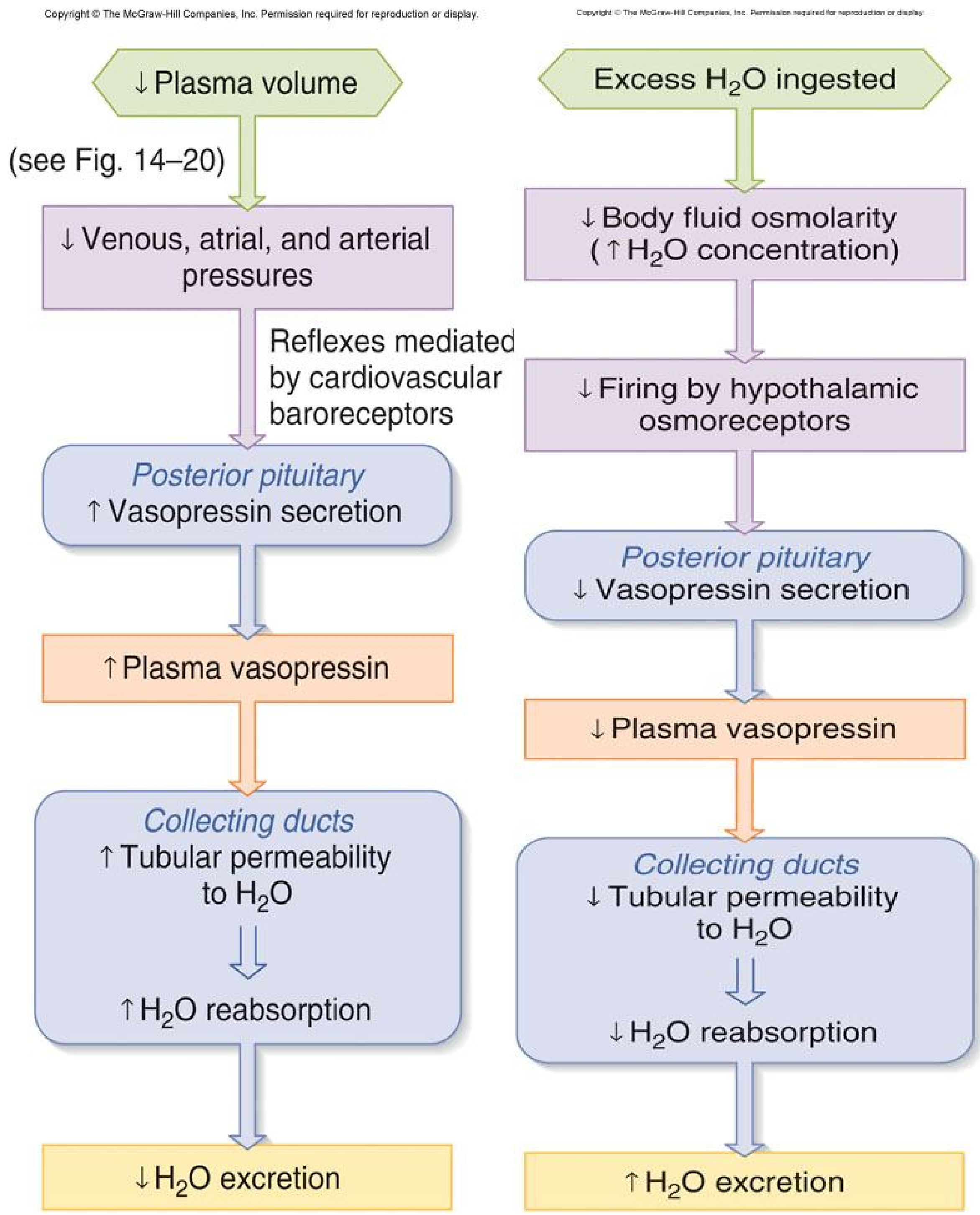
- To remain properly hydrated, water intake must equal water output
- Water intake sources
  - Ingested fluid (60%) and solid food (30%)
  - Metabolic water or water of oxidation (10%)
- Water output
  - Urine (60%) and feces (4%)
  - Insensible losses (28%), sweat (8%)
- Increases in plasma osmolality trigger thirst and release of antidiuretic hormone (ADH)

# Regulation of Water Intake: Thirst Mechanism



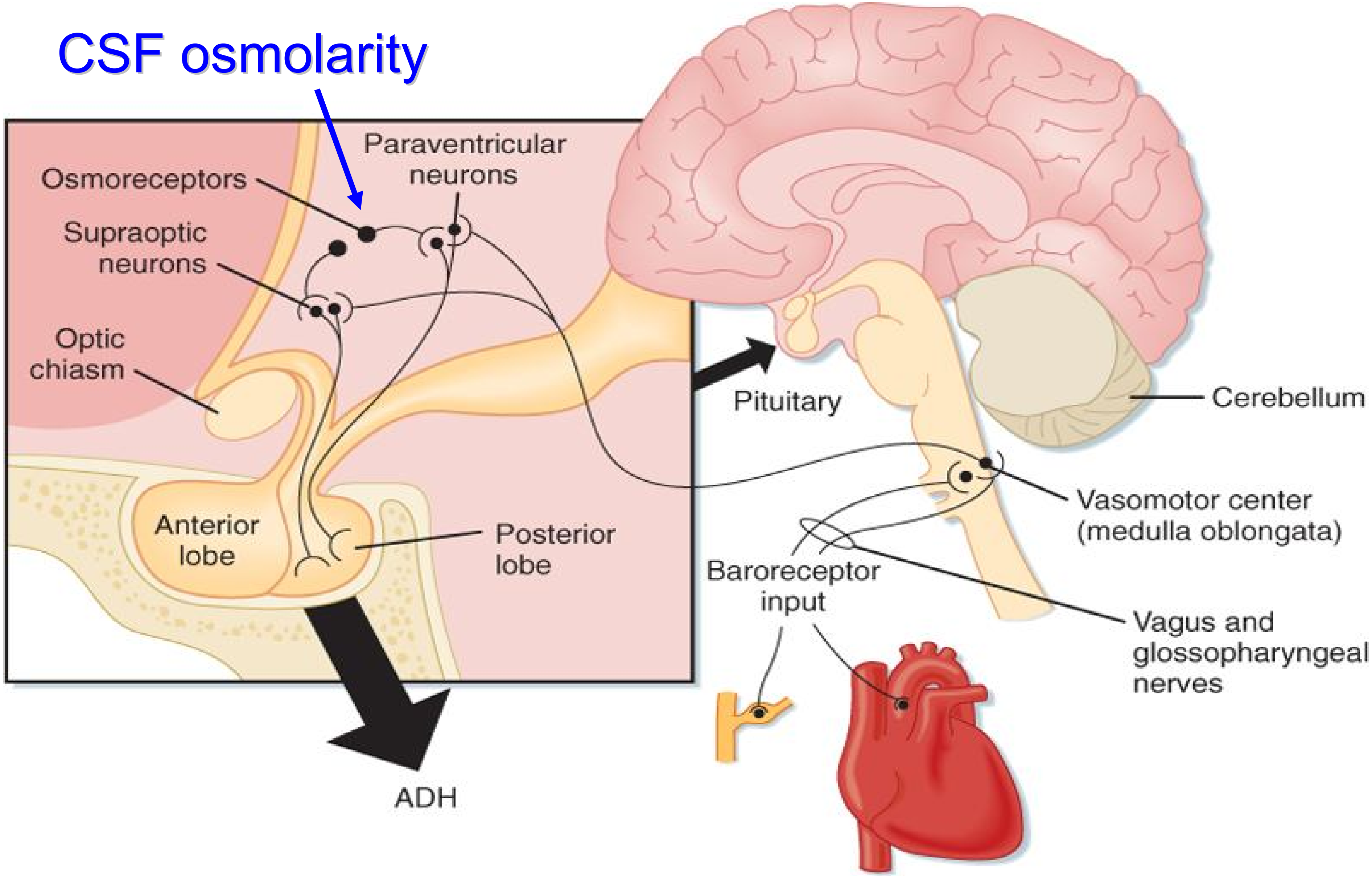
# Regulation of water balence

ADH stimulated by baroreceptor and osmoreceptor

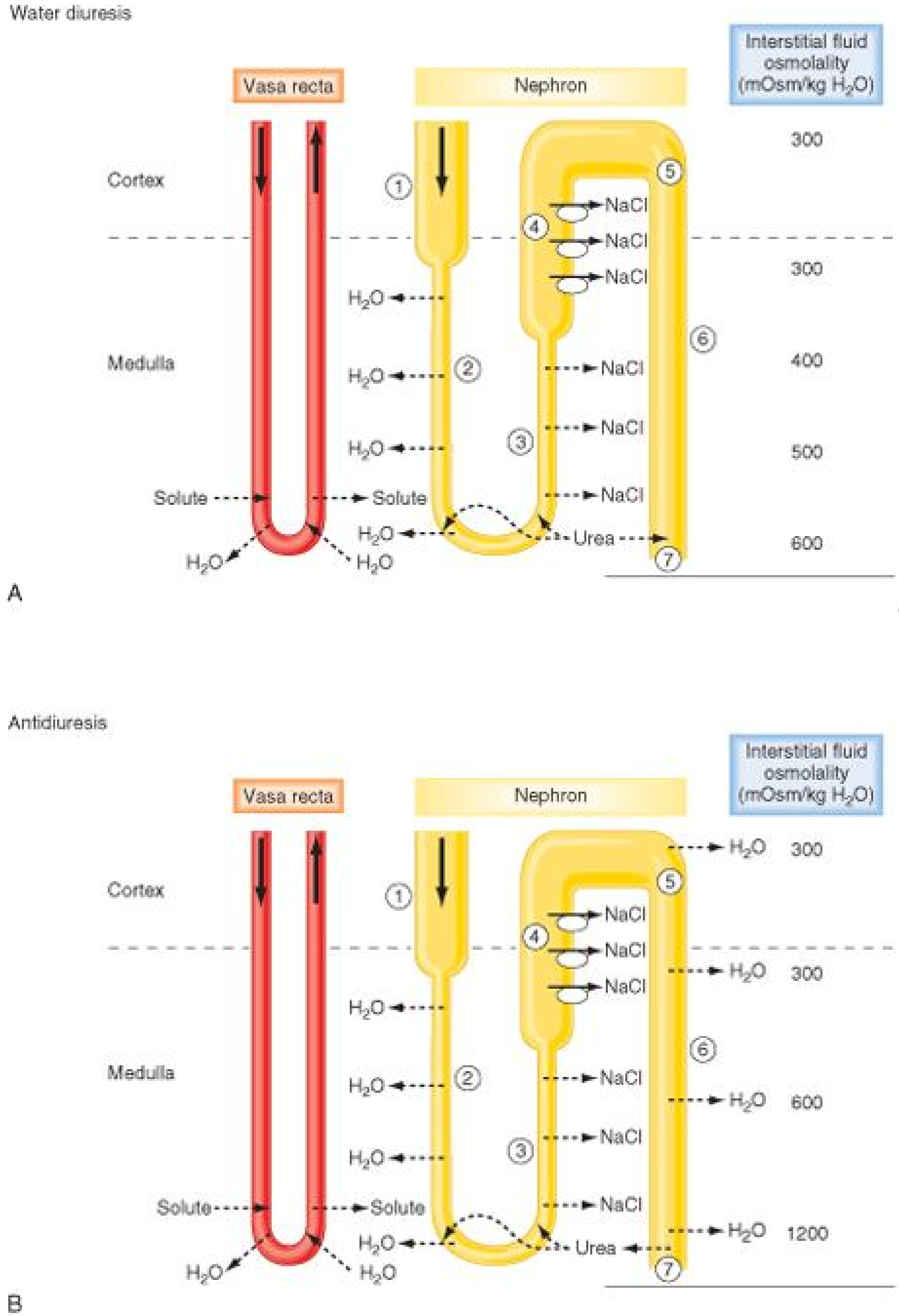


# ADH stimulated by baroreceptor and osmoreceptor

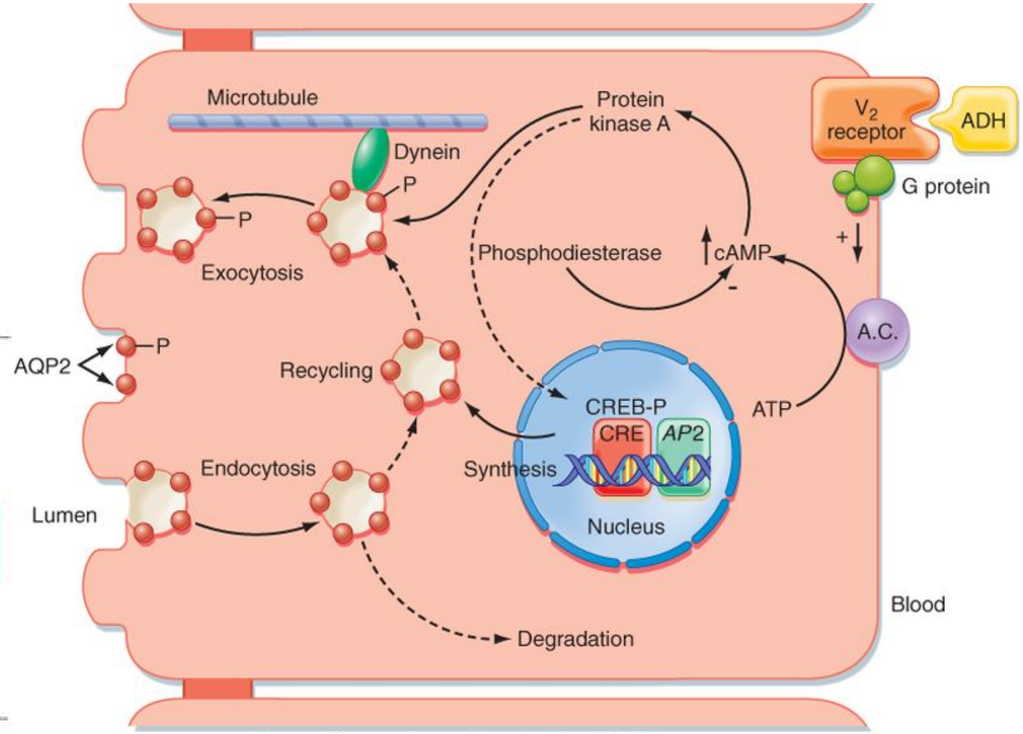
CSF osmolarity




Koeppen & Stanton: Berne and Levy Physiology, 6th Edition.


Water diuresis
Vasa recta
Nephron
Interstitial fluid osmolality (mOsm/kg $H_2O$)
Cortex
Medulla
300
300
400
500
600
NaCl
$H_2O$
Solute
Urea
A
Antidiuresis
Vasa recta
Nephron
Interstitial fluid osmolality (mOsm/kg $H_2O$)
Cortex
Medulla
300
300
600
1200
NaCl
$H_2O$
Solute
Urea
B



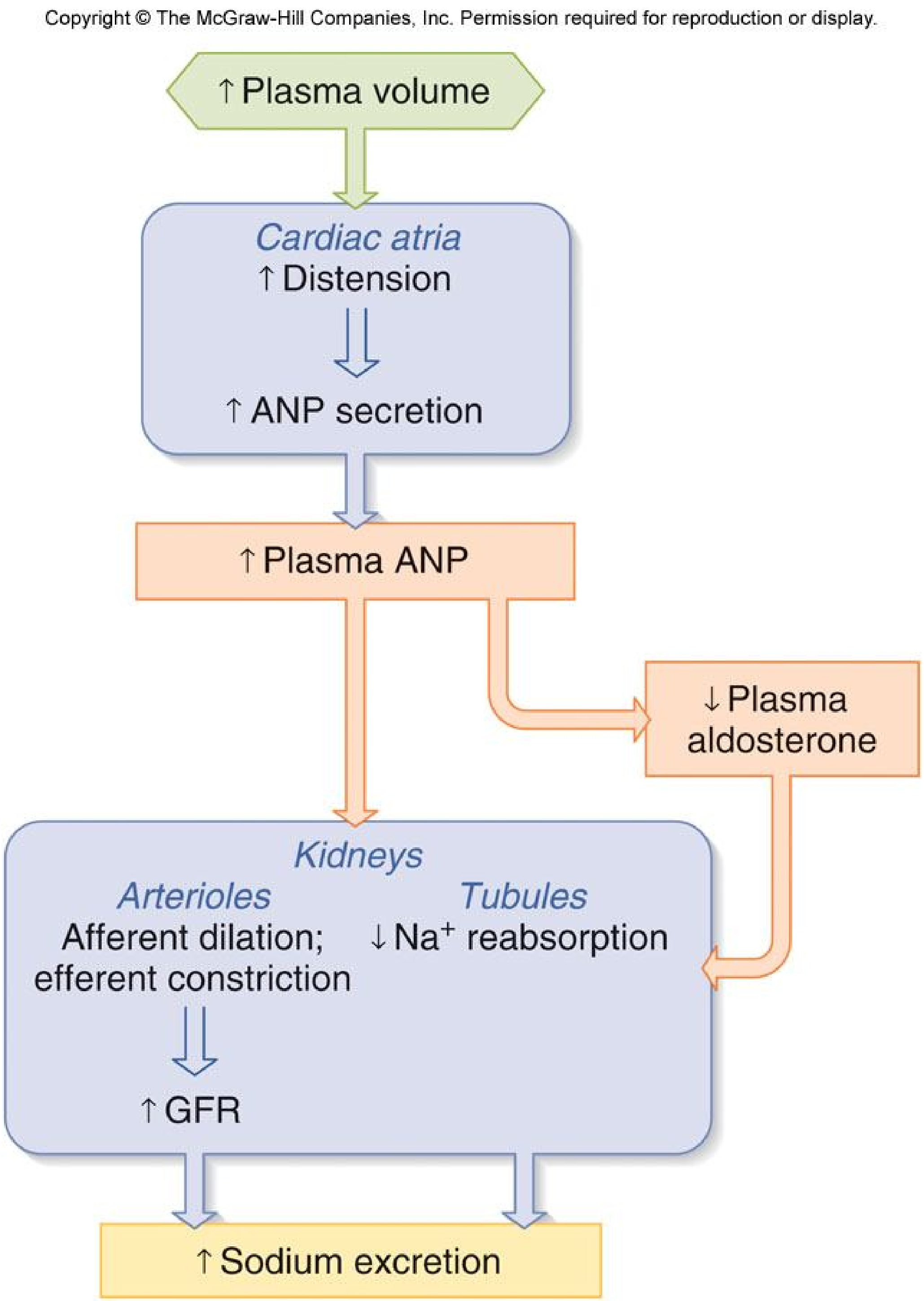

Microtubule
Protein kinase A
$V_2$ receptor
ADH
Dynein
G protein
Exocytosis
Phosphodiesterase
cAMP
A.C.
AQP2
Recycling
CREB-P
CRE
AP2
ATP
Endocytosis
Synthesis
Lumen
Nucleus
Blood
Degradation

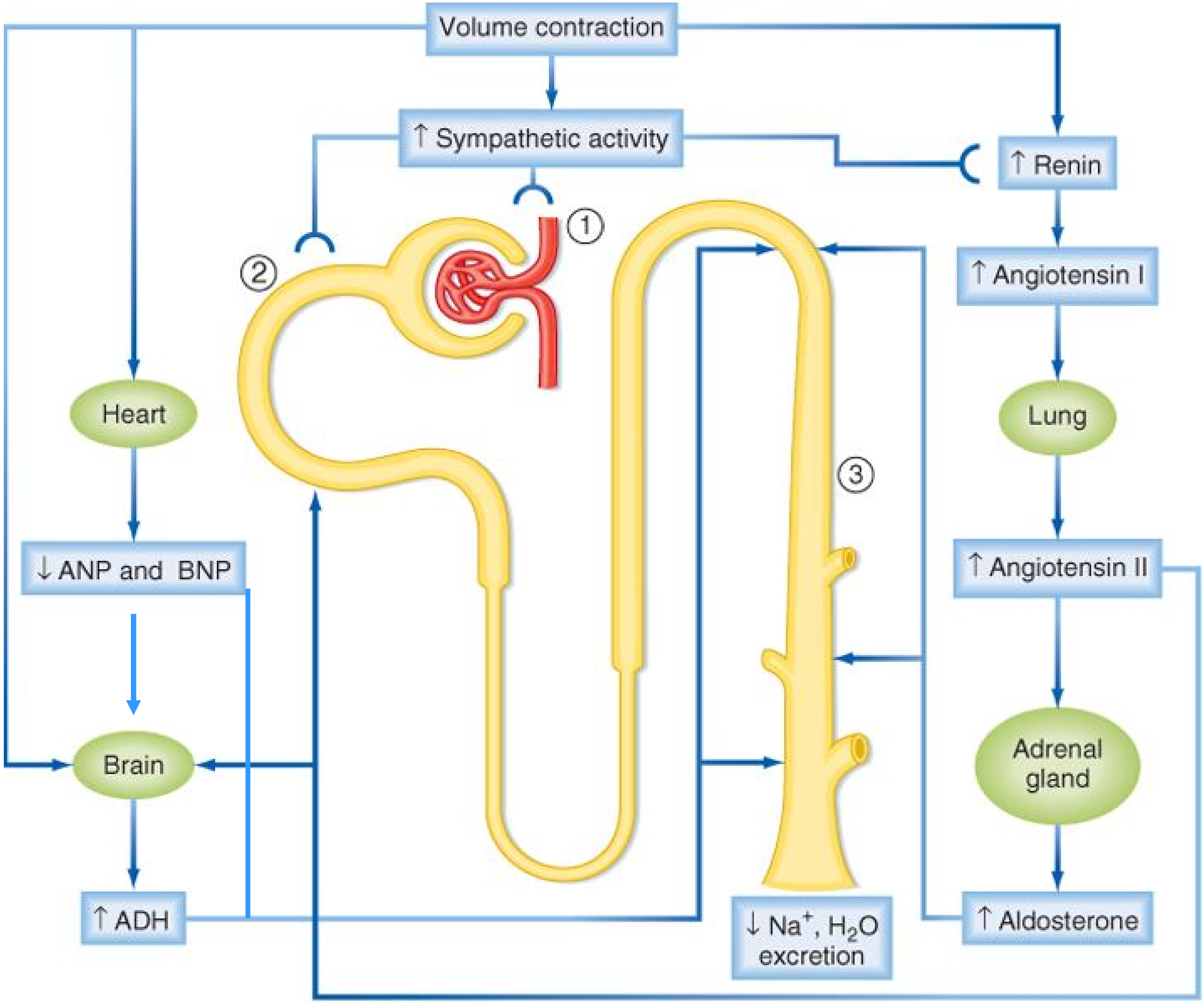
# Atrial natriuretic peptide (ANP)

- Produced by **atrial myocytes in response to stretch**
- Antagonistic effects **to RAAS**
- Functions

  - Vasodilator
  - Vasodilation of afferent but constriction of efferent
  - Promotes NaCl and water excretion by the kidney
  - Inhibition of renin, aldosterone and ADH secretion.
  - Inhibition of NaCl reabsorption by medullary collecting duct.

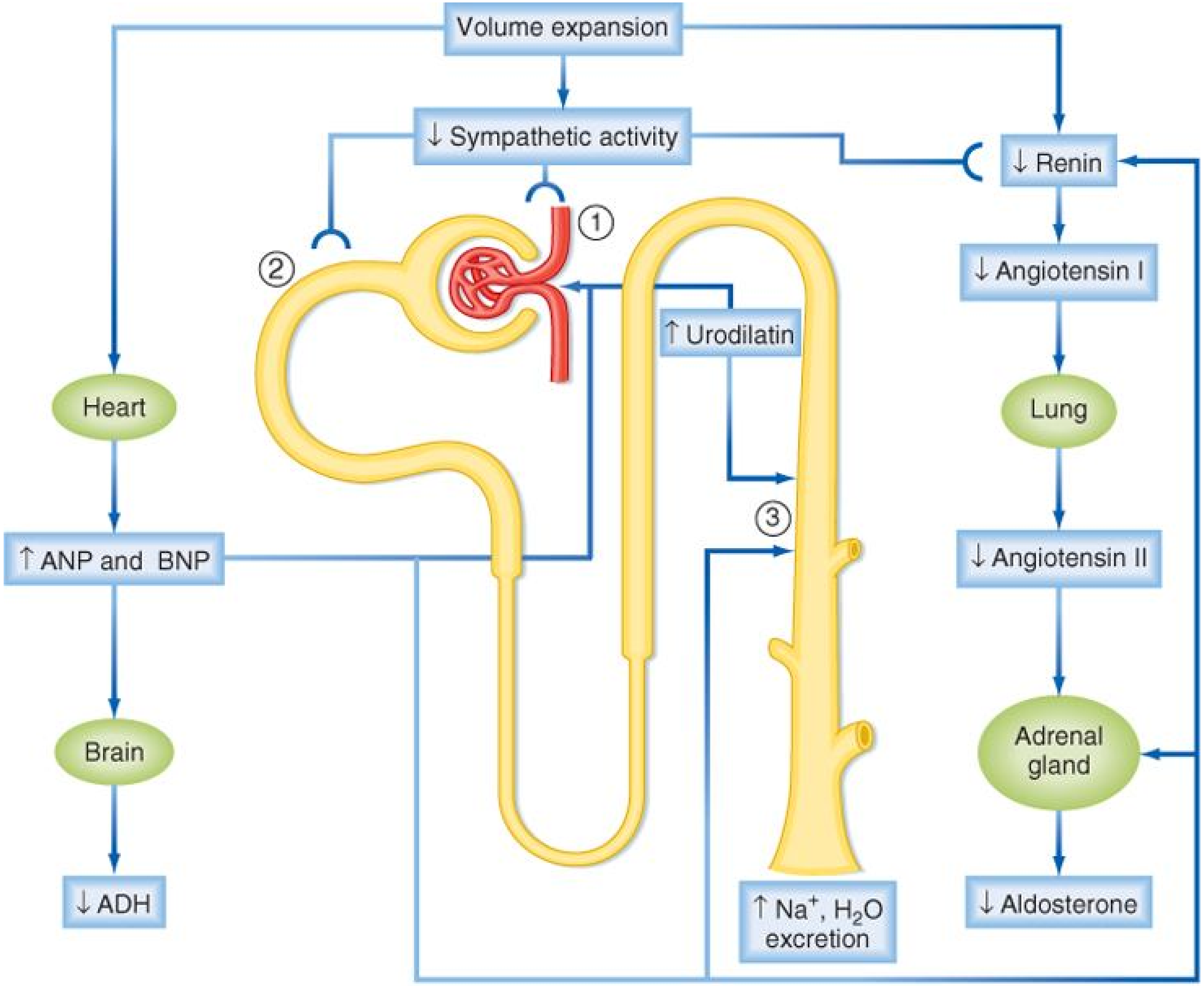
# Control of renal functions in volume expansion






$$\downarrow U_{Na^+}\dot{V} = \downarrow GFR \times P_{Na^+} - \uparrow R$$

Koeppen & Stanton: Berne and Levy Physiology, 6th Edition.




$$U_{Na^+}\dot{V} = \uparrow GFR \times P_{Na^+} - \downarrow R$$

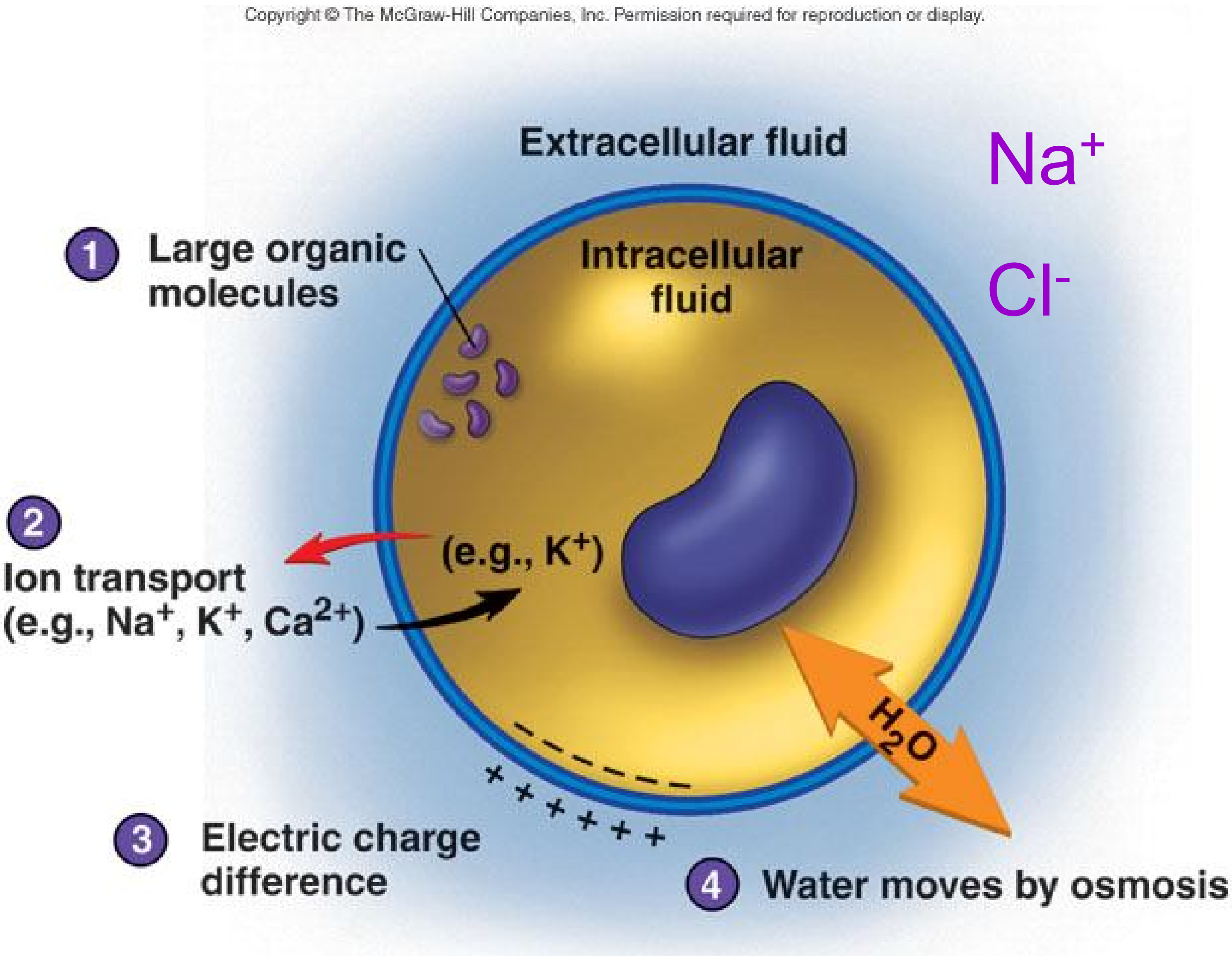
# Sodium in Fluid and Electrolyte balance

- Sodium holds a **central position in fluid and electrolyte balance**
- Sodium salts:
  - Account for 90-95% of all solutes in the ECF
  - Contribute 280 mOsm of the total 300 mOsm ECF solute concentration
- Sodium is the single most abundant cation in the ECF
- Sodium is the only cation exerting significant osmotic pressure
- Changes in plasma sodium levels affect:
  - Plasma volume, blood pressure
  - ICF and interstitial fluid volumes

# Sodium - Functions

- Membrane potentials
- Accounts for 90 - 95% of osmolarity of ECF
- Na+- K+ pump
  - exchanges intracellular Na+ for extracellular K+
  - creates gradient for cotransport of other solutes (glucose)
  - generates heat
- $NaHCO_3$ has major role in buffering pH

# Regulation of ICF and ECF



# Control of ECF volume and Regulation of Renal $Na^+$ excretion



| Table 14–4 | Daily Sodium Chloride Intake and Loss |
|---|---|
| *Intake* | |
| Food | 10.50 g |
| *Output* | |
| Sweat | 0.25 g |
| Feces | 0.25 g |
| Urine | 10.00 g |
| **Total** | **10.50 g** |

# Control of ECF volume and Regulation of Renal Na+ excretion

- $Na^+$ excreted = $Na^+$ filtered – $Na^+$ reabsorbed
- Water excreted = water filtered – water reabsorbed

What kinds of variables are receptor sensing?

- pressure, stretch, osmolarity, ion conc

# Volume sensors

- **Vascular low pressure (Volume receptor)**
  - cardiac atria
  - pulmonary vessels
  - large veins
- **Vascular high pressure (baroreceptor)**
  - carotid sinus
  - aortic arch
  - juxtaglomerular apparatus
- **Hepatic sensors respond to BP or $Na^+$** in portal blood
- **CNS $Na^+$ sensor respond to $Na^+$** in carotid a. or cerebrospinal fluid (CSF)

# Volume sensor signals

With negative $Na^+$ balance, baroreceptors stimulate renal sympathetic nerves.

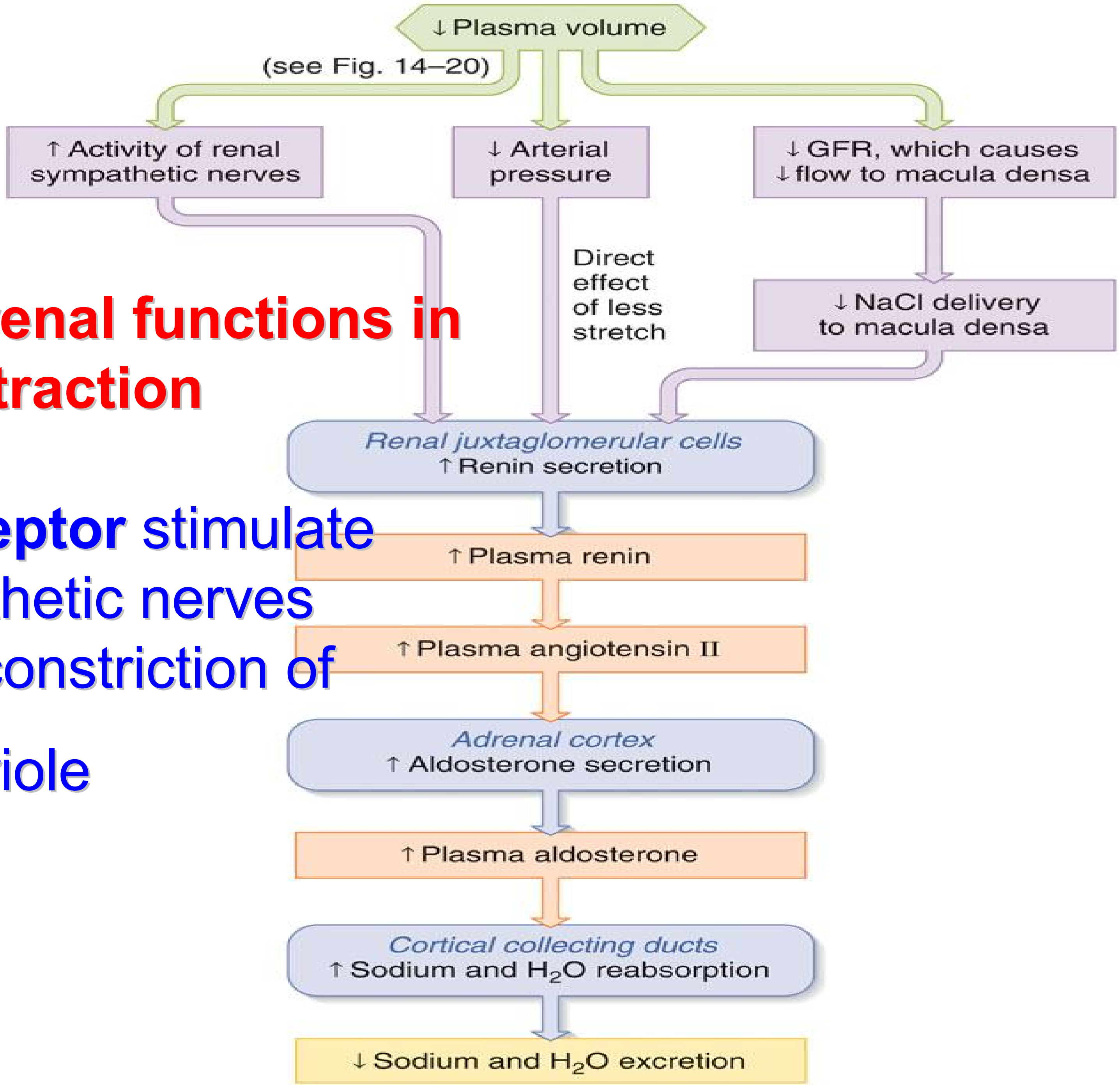
- NE directly acts on α-adrenergic receptors of afferent and efferent arterioles.
- Renin secretion is stimulated via β-adrenergic receptors.
- NaCl reabsorption is directly stimulated via α-adrenergic receptors.

Hormones – RAAS, ADH, ANP

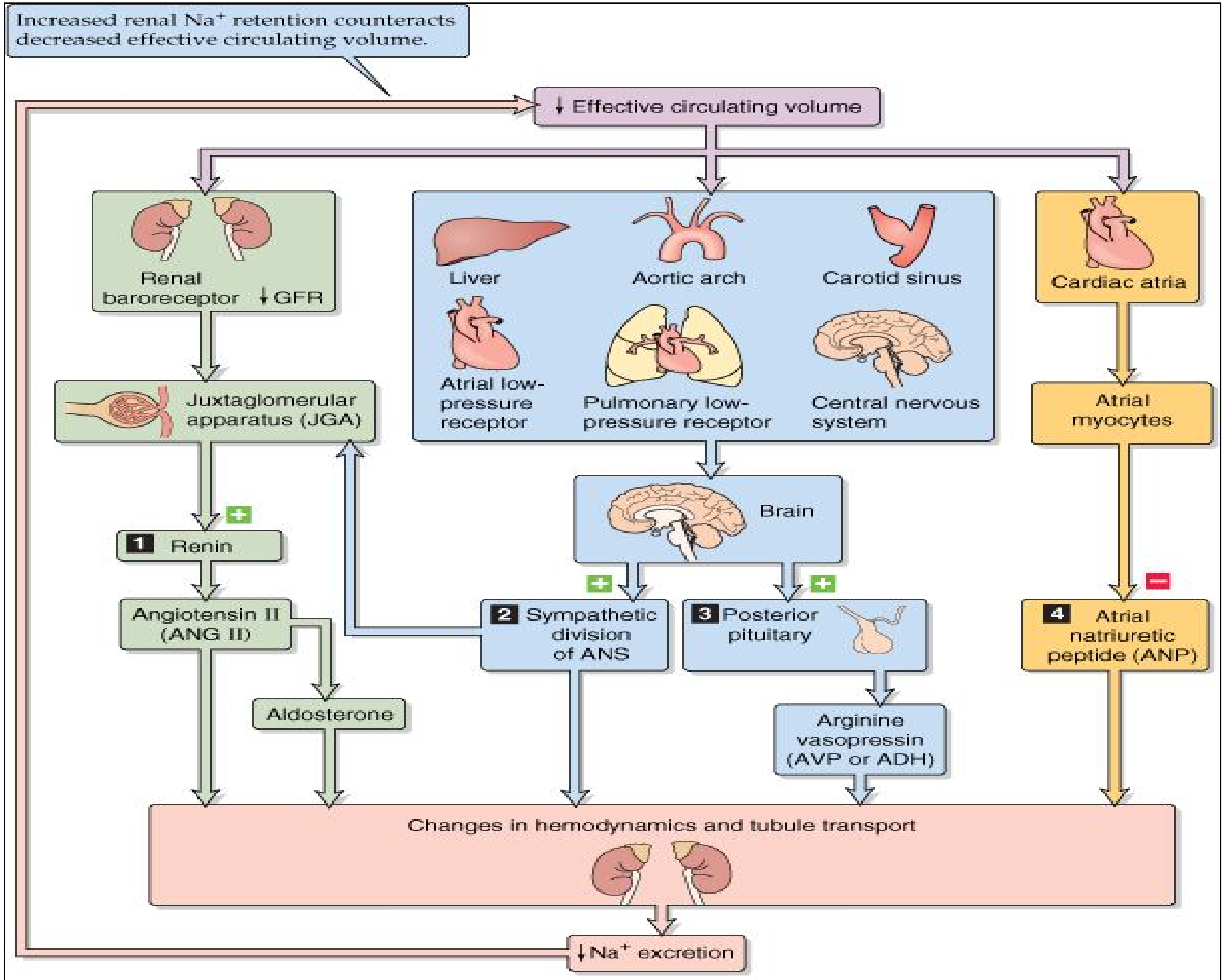
# Control of renal functions in volume contraction

**Volume receptor** stimulate renal sympathetic nerves followed by constriction of

afferent arteriole



# Control of effective circulating volume



# Renal Clearance

- **The volume of blood that would be completely 'cleared' of a substance in a given time by the kidneys.**

- **Calculated from:** $Px \times PV = Ux \times UV$

  Ux, urine con of substance; UV, urine vol/min

  Px, plasma con of substance; PV, plasma vol filtered/min

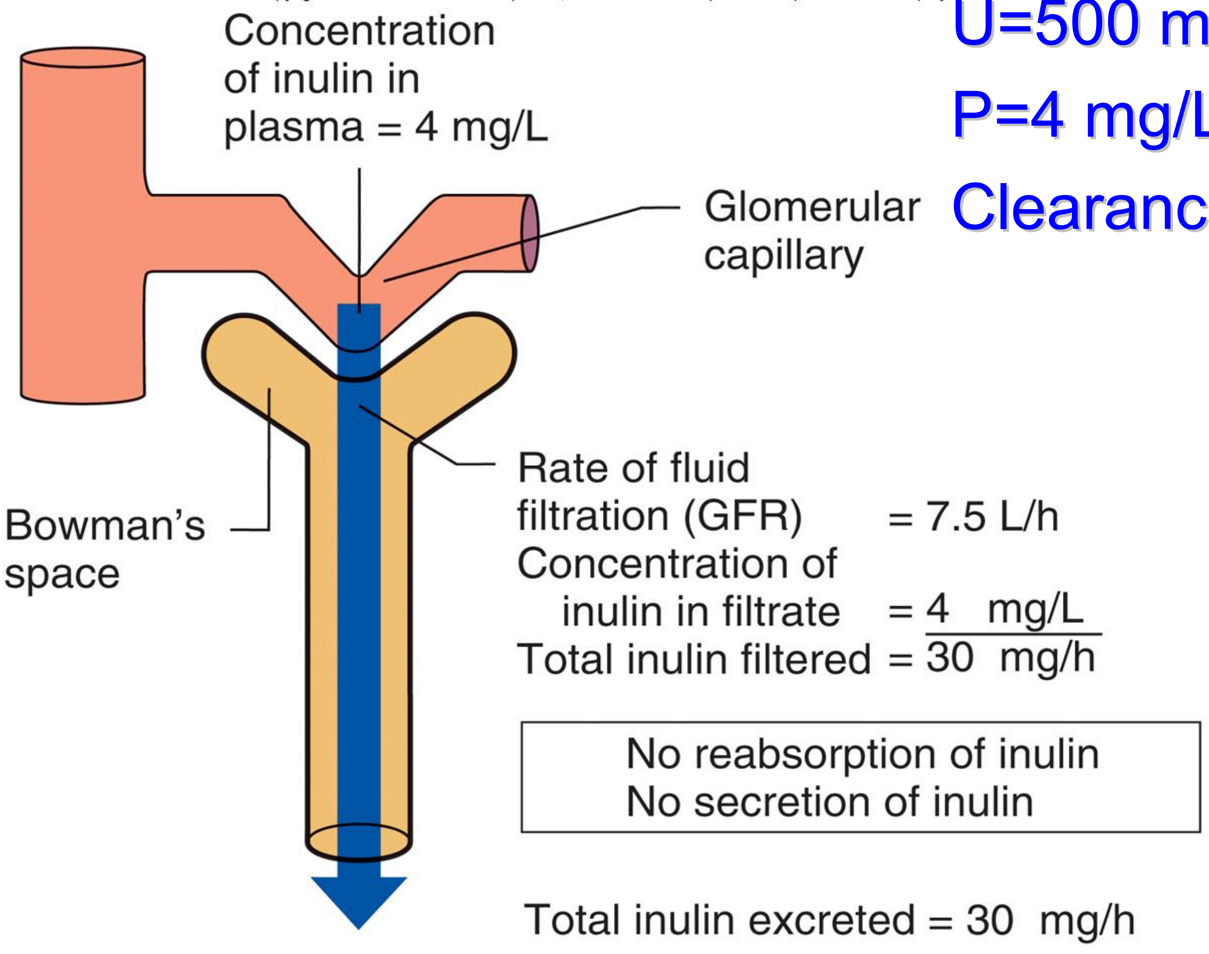
$$\text{Clearance (ml/min)} = \frac{\text{Ux (mg/ml)} \times \text{UV (ml/min)}}{\text{Px (mg/ml)}}$$

(**PV**)

# Use of inulin clearance for GFR

- Inulin: filtered, but not secreted or absorbed
- Therefore clearance ≈ amount filtered
- So inulin clearance = glomerular filtration rate (GFR)






U=500 mg/L, V=60 ml/ h

P=4 mg/L

Clearance=7.5 L/h (125 ml/min)

# Use of PAH clearance for RPF

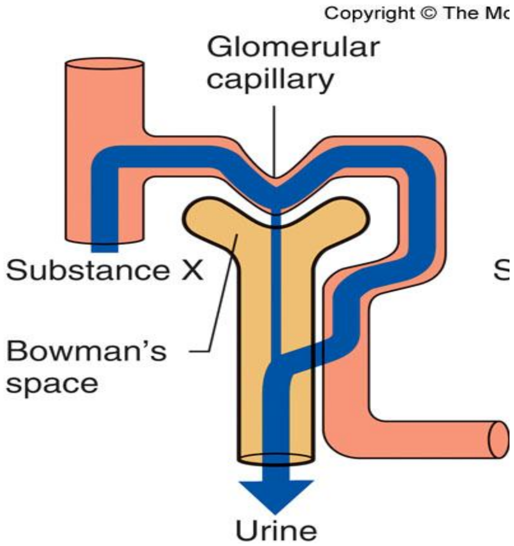
- Para-amino-hippuric acid (PAH): filtered and secreted. Almost all is cleared in one pass through the kidneys
- So PAH clearance = effective renal plasma flow rate (ERPF)
- Extraction ratio of PAH=0.9
- To obtain renal blood flow,

  adjust for haematocrit

  RPF = $C_{PAH}$/0.9 = 594ml/min/0.9=660ml/min

  RBF = (ERPF/0.9)x [100/(100–Ht)]

  =1200ml



# Filtration fraction

The fraction of the plasma that is filtered in the glomeruli

FF = GFR / RPF

125 / 660 = 0.19 = 19%

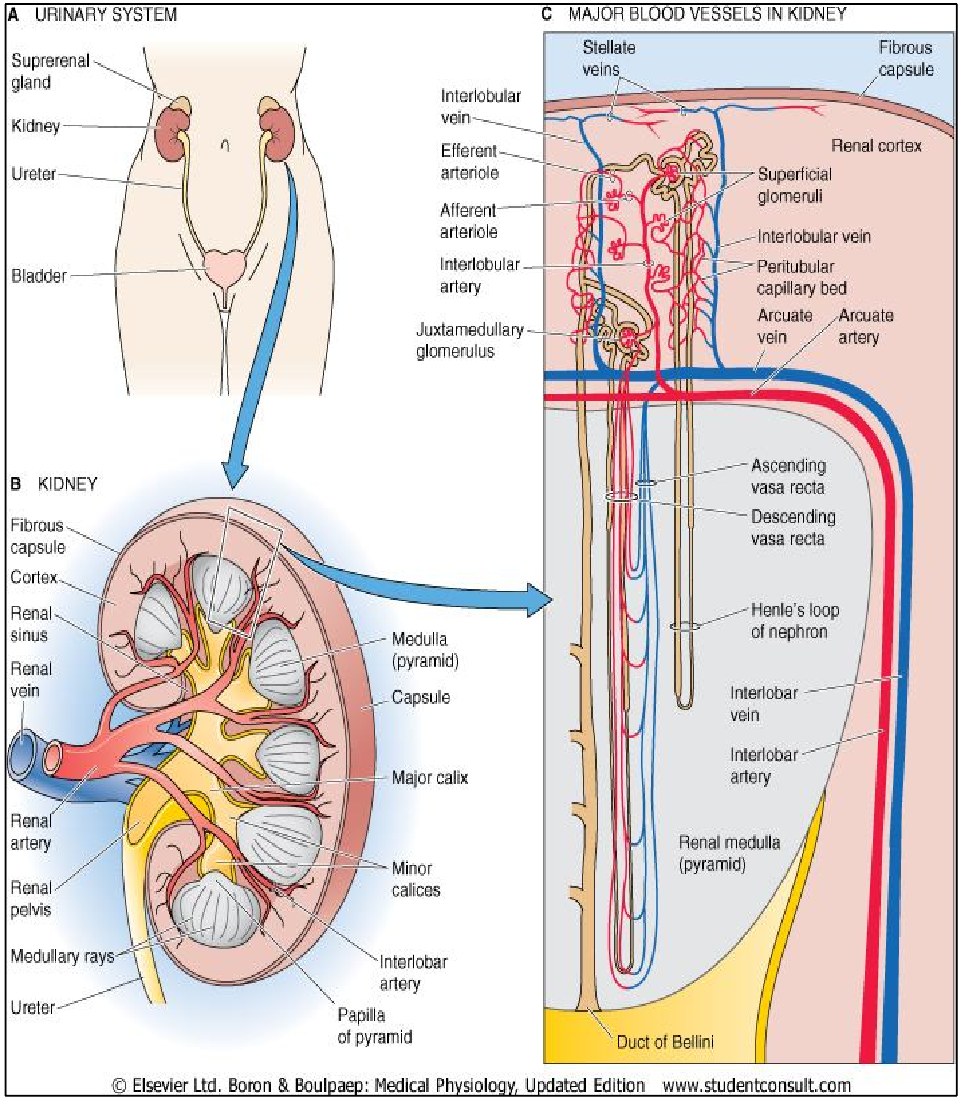
Normal 0.16 - 0.20

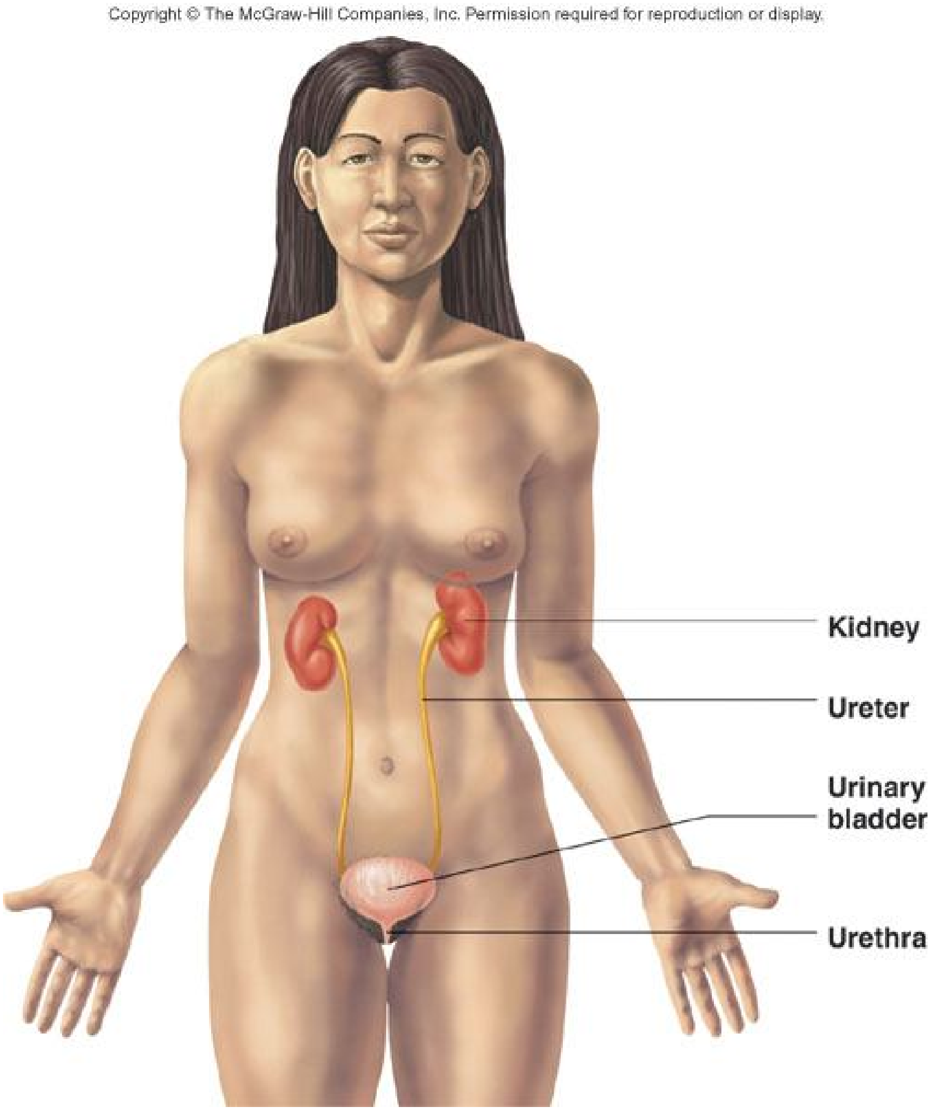
# Endogenous clearances

- **Creatinine:** used clinically to measure renal function

  (Creatinine clearance is close to GFR)
- **Glucose clearance normally zero:** all filtered glucose is reabsorbed
- **“Free water clearance”** is a measure of the tonicity of the urine and is calculated from the clearance of total osmoles

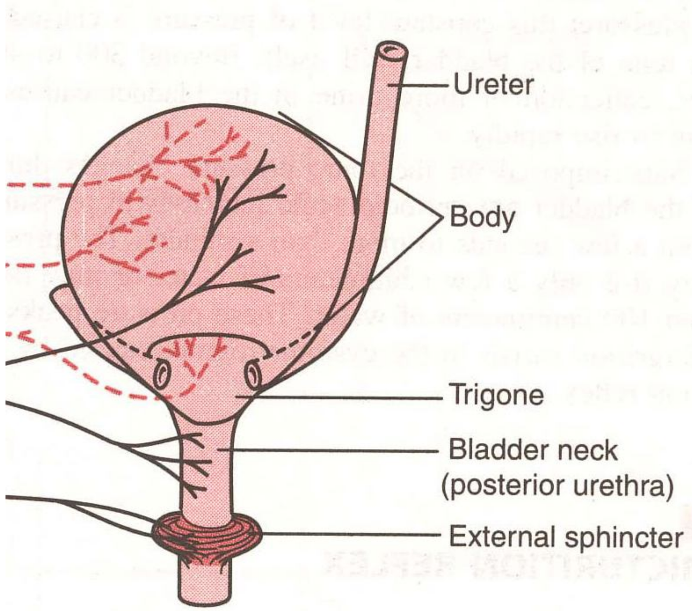
# Micturition



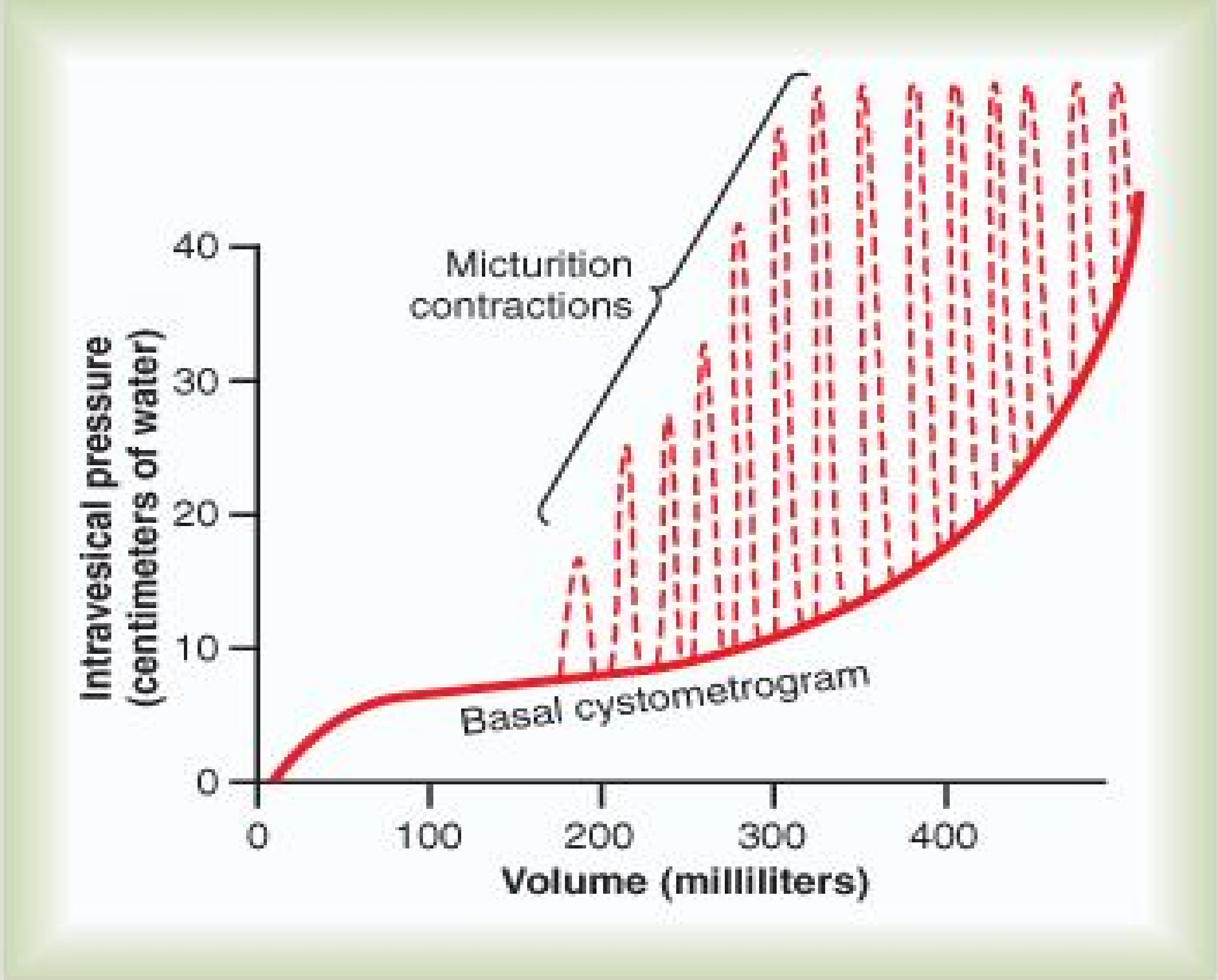



# Micturition (Voiding or Urination)

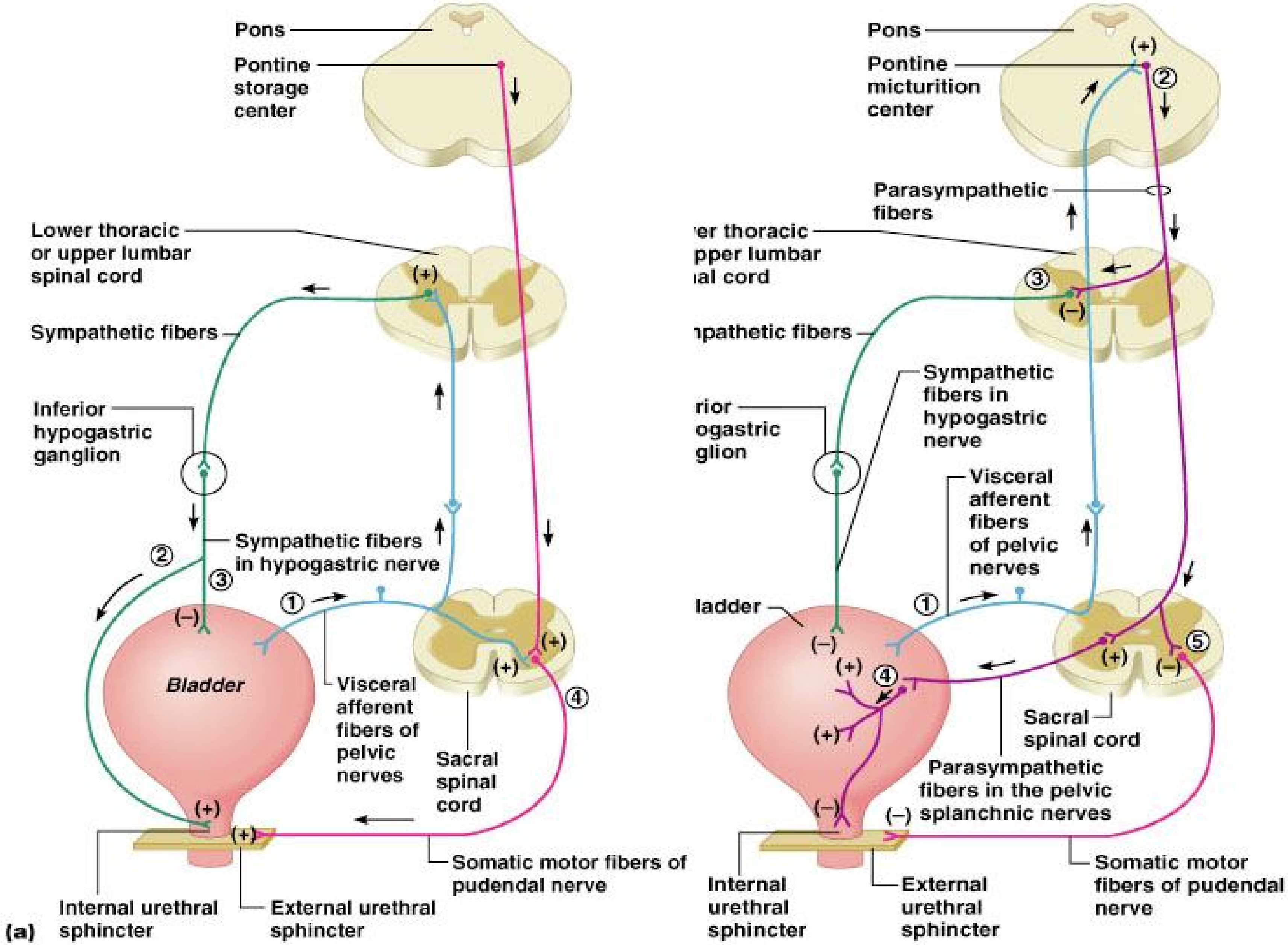
- Bladder can hold 250 - 400ml
- Greater volumes stretch bladder walls initiates micturation reflex:
- Spinal reflex
  - Parasympathetic stimulation causes bladder to contract
  - Internal sphincter opens
  - External sphincter relaxes due to inhibition



# Pressure-volume graph for normal human bladder



# Micturation reflex

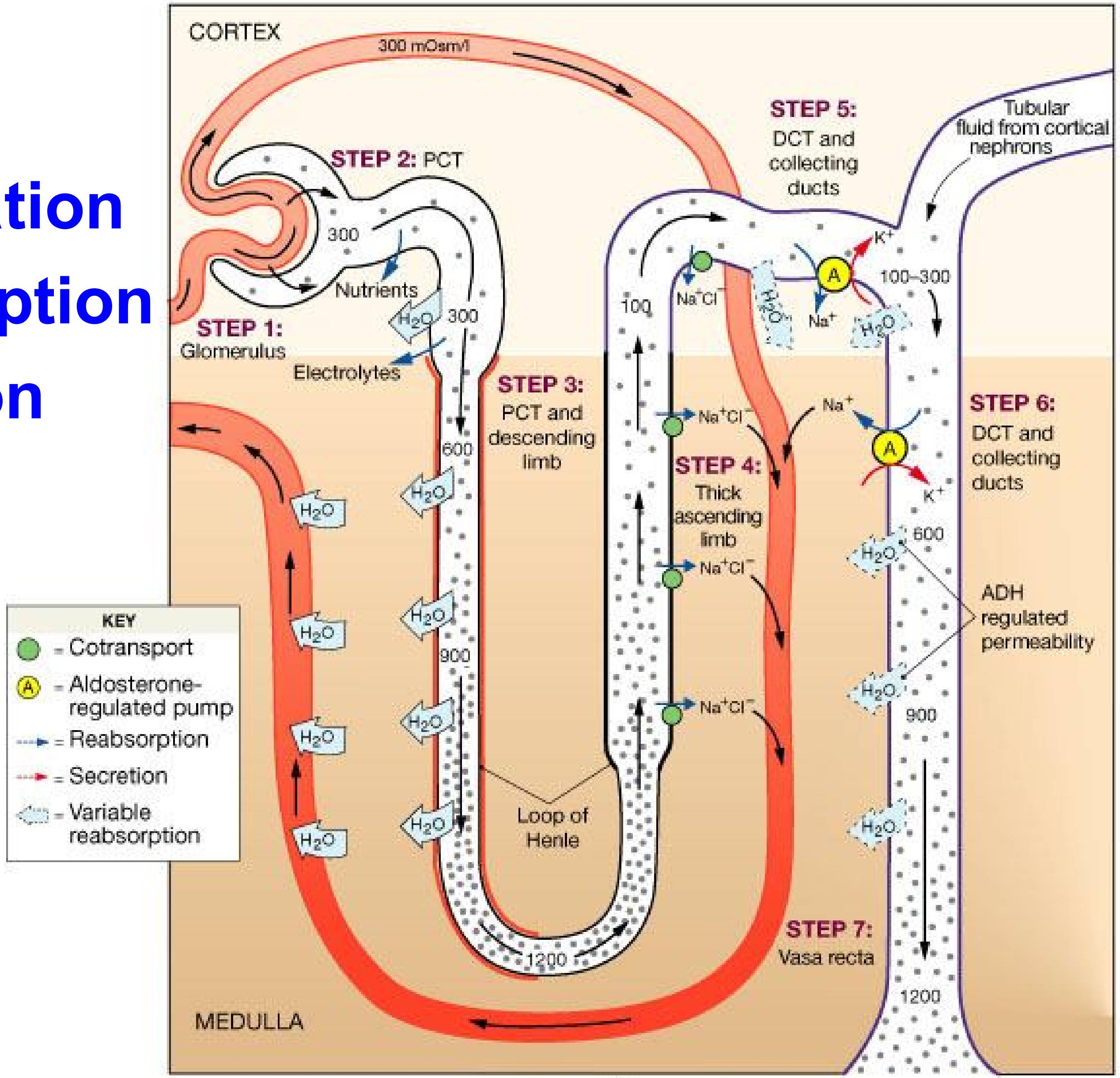


# Summary

**Glomerular filtration**

**Tubular reabsorption**

**Tubular secretion**




(a)