# Adrenal glands. Stress.

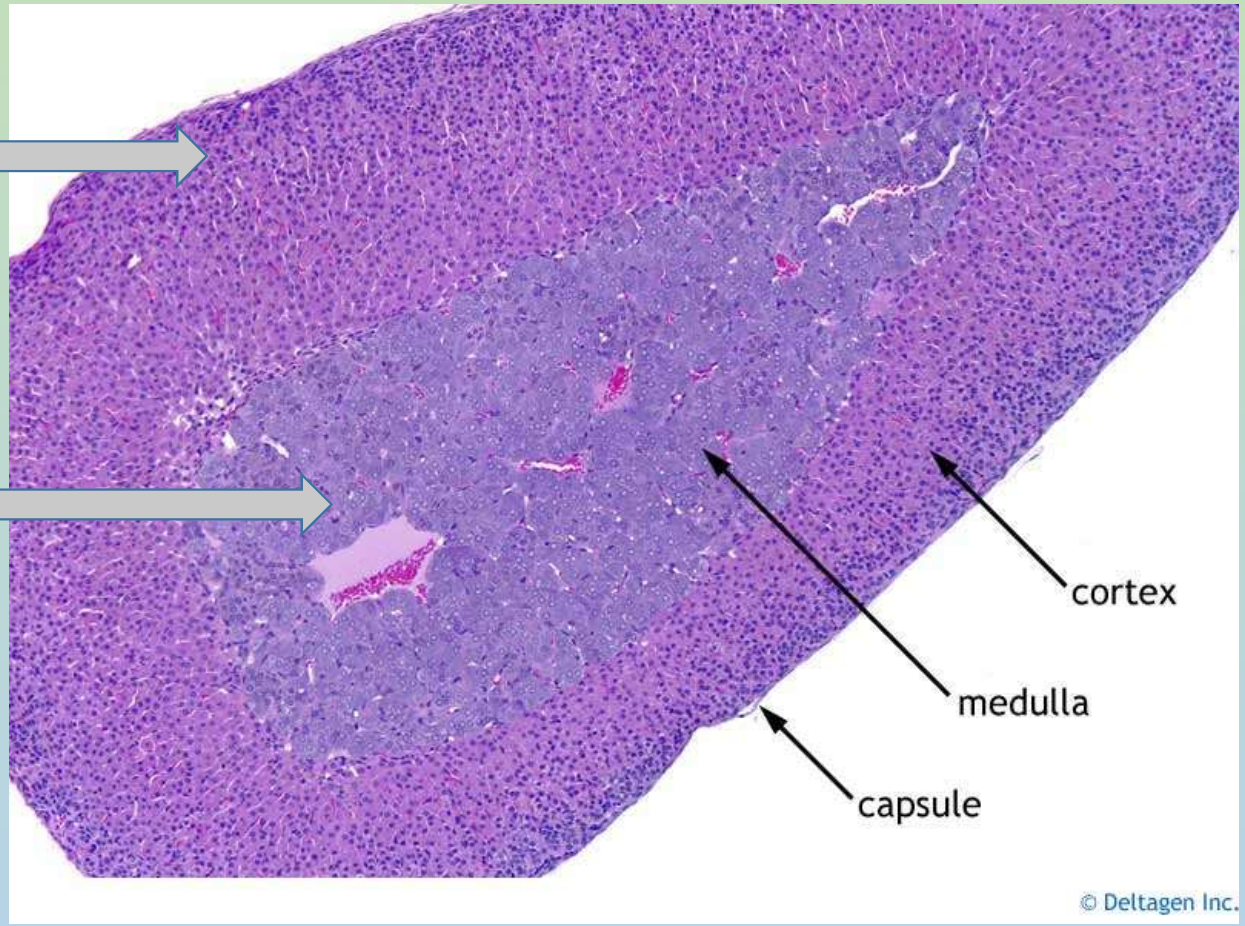
# Adrenal glands

Adrenal cortex - Steroid hormones
- Glucocorticoids
- Mineralocorticoids
- Androgens

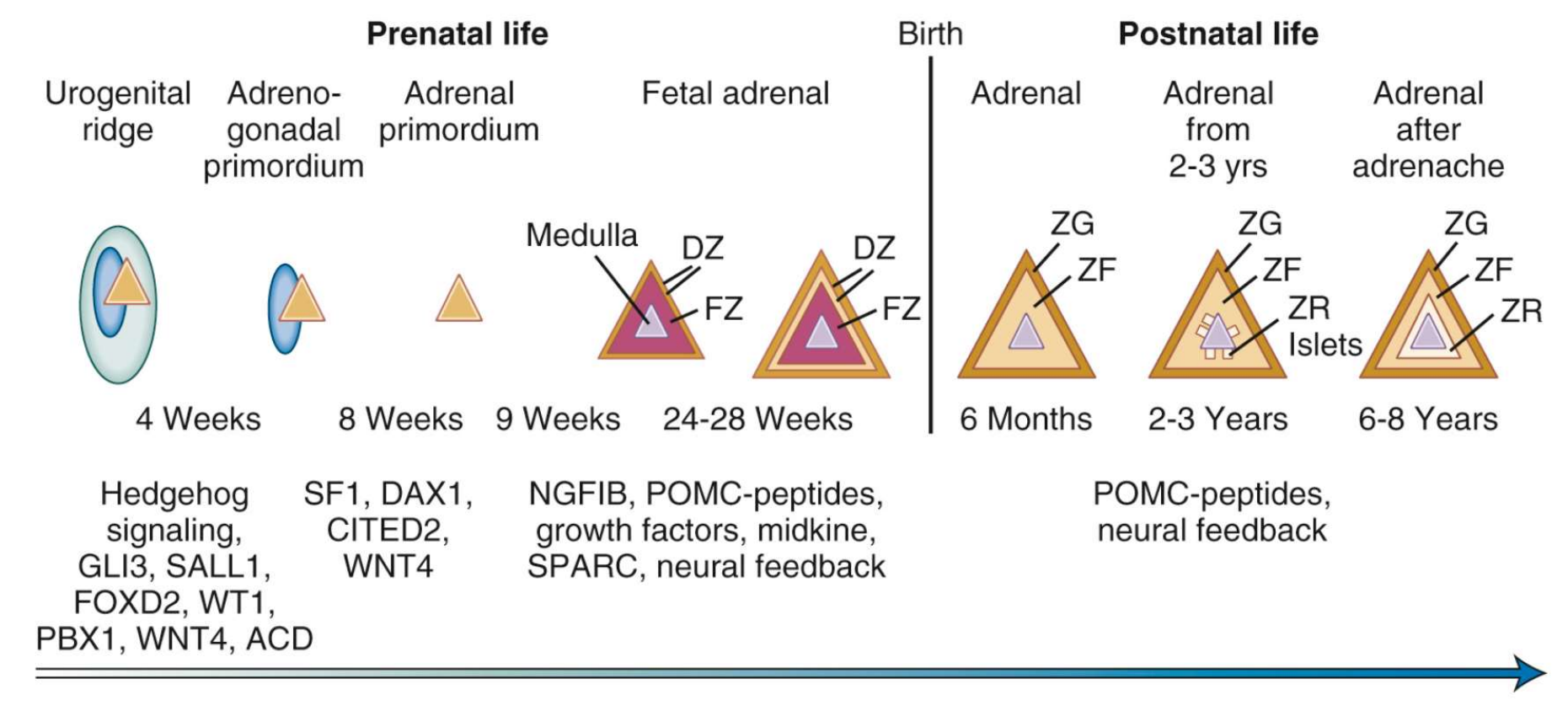
Adrenal medulla
- Catecholamines
  - Epinephrine (adrenaline)
  - Norepinephrine (noradrenaline)
  - Dopamine

Corticomedullary portal system

Function
- Stress response
- $Na^+$, $K^+$, ECT
- Blood pressure



# Fetal adrenal gland development

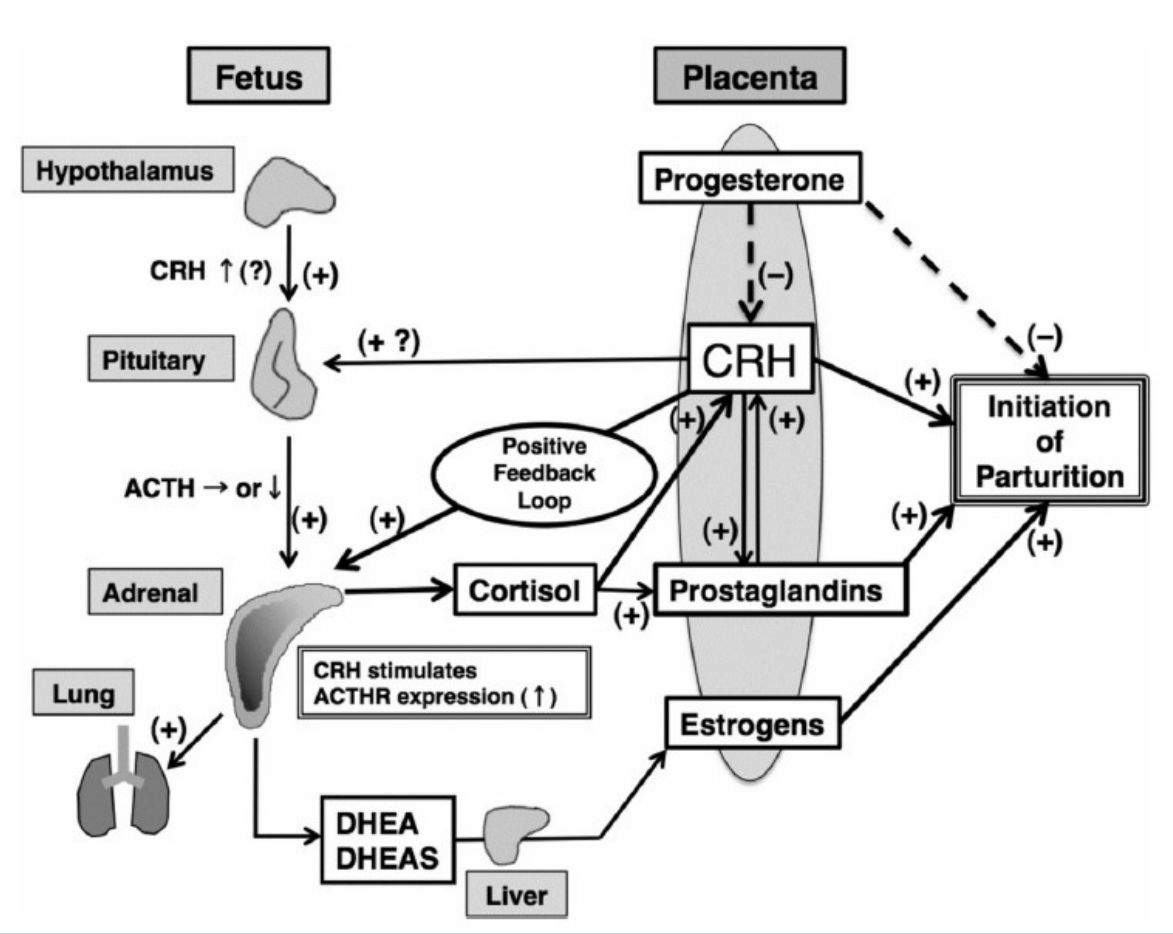



**During second trimester the inner fetal zone grows bigger and produces high amount of DHEA and DHEAS.**

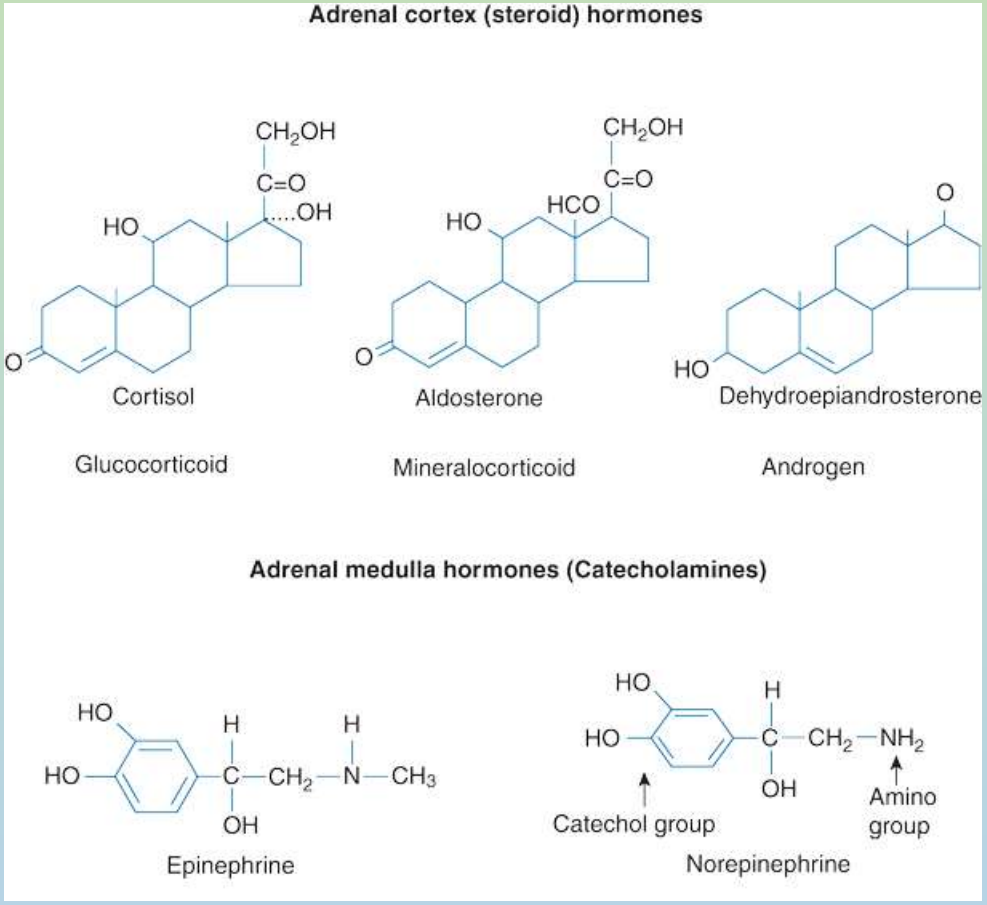
# Fetal adrenal gland and its importance

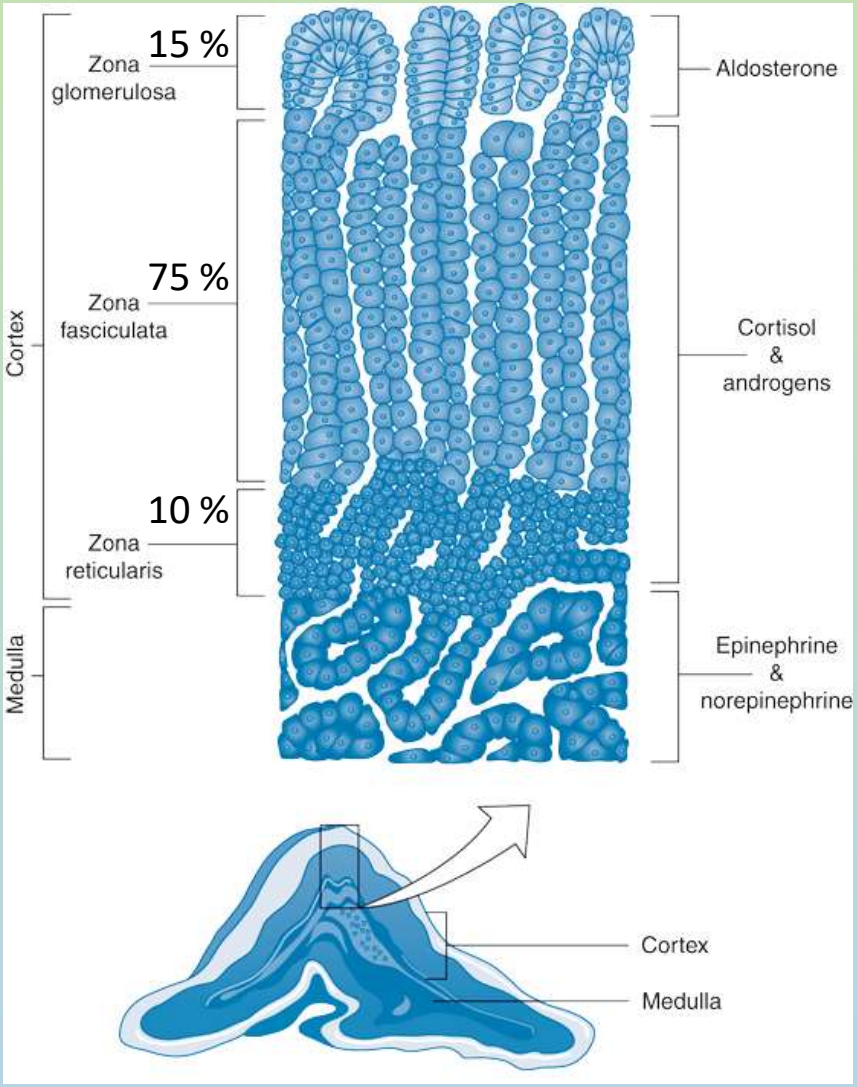
- Placental CRH stimulates production of DHEA, corresponding sulphate and cortisol in fetal adrenal gl.
- DHEA/DHEAS is in placenta converted to estrogen (preparation and promotion of birth)
- Cortisol upregulates ACTHR, but also prostaglandin and uterotonics in placenta (birth)
- Cotisol is necessary for maturation of fetal lungs

- Progesterone inhibits placental CRH



# Adrenal gland hormones




ER

Lipid droplets

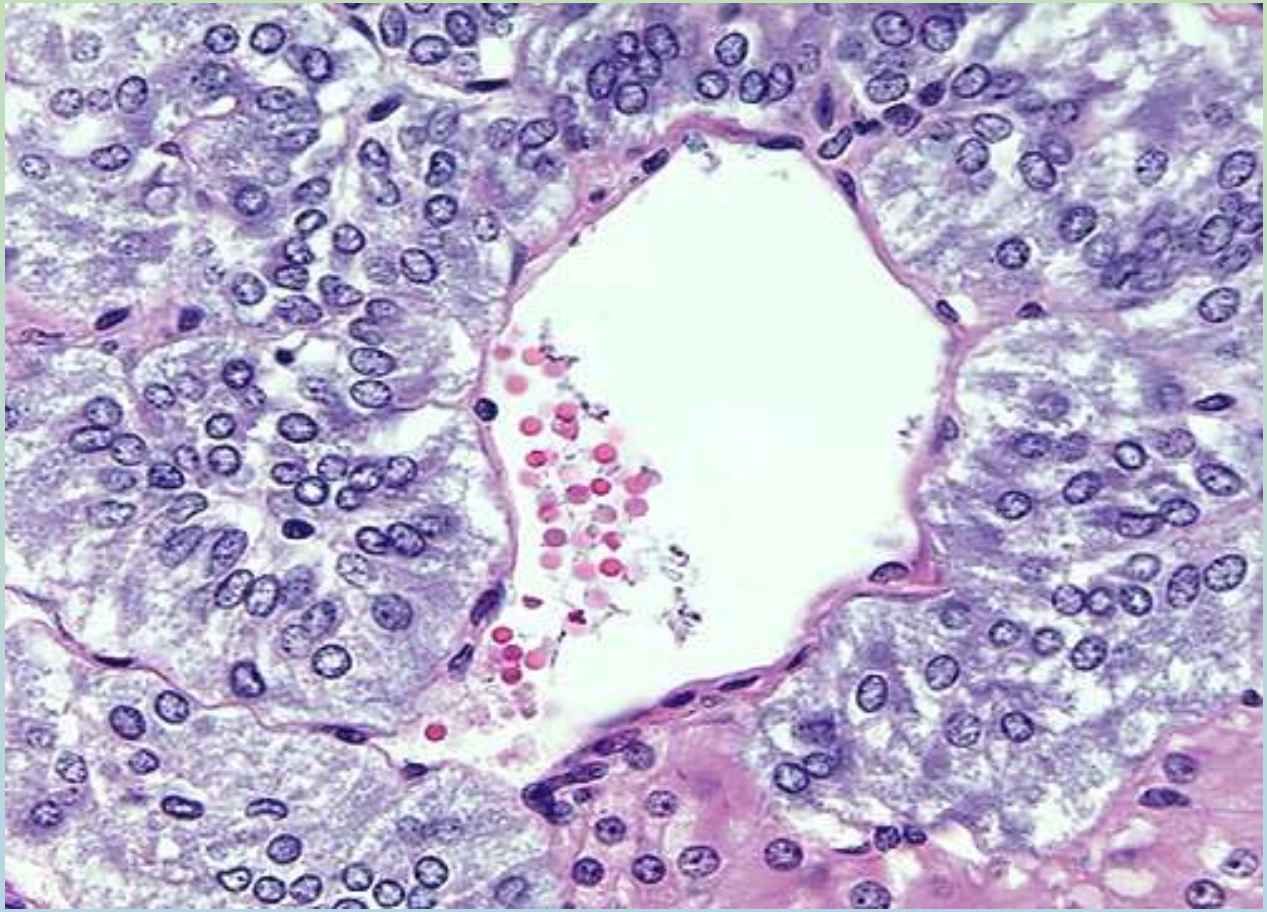
**Functional architecture of adrenal gland allows transport of steroid hormones into medulla and influences activity of enzymes connected to catecholamine synthesis.**

# Adrenal medulla

Adrenaline secerning cells
(90 %)

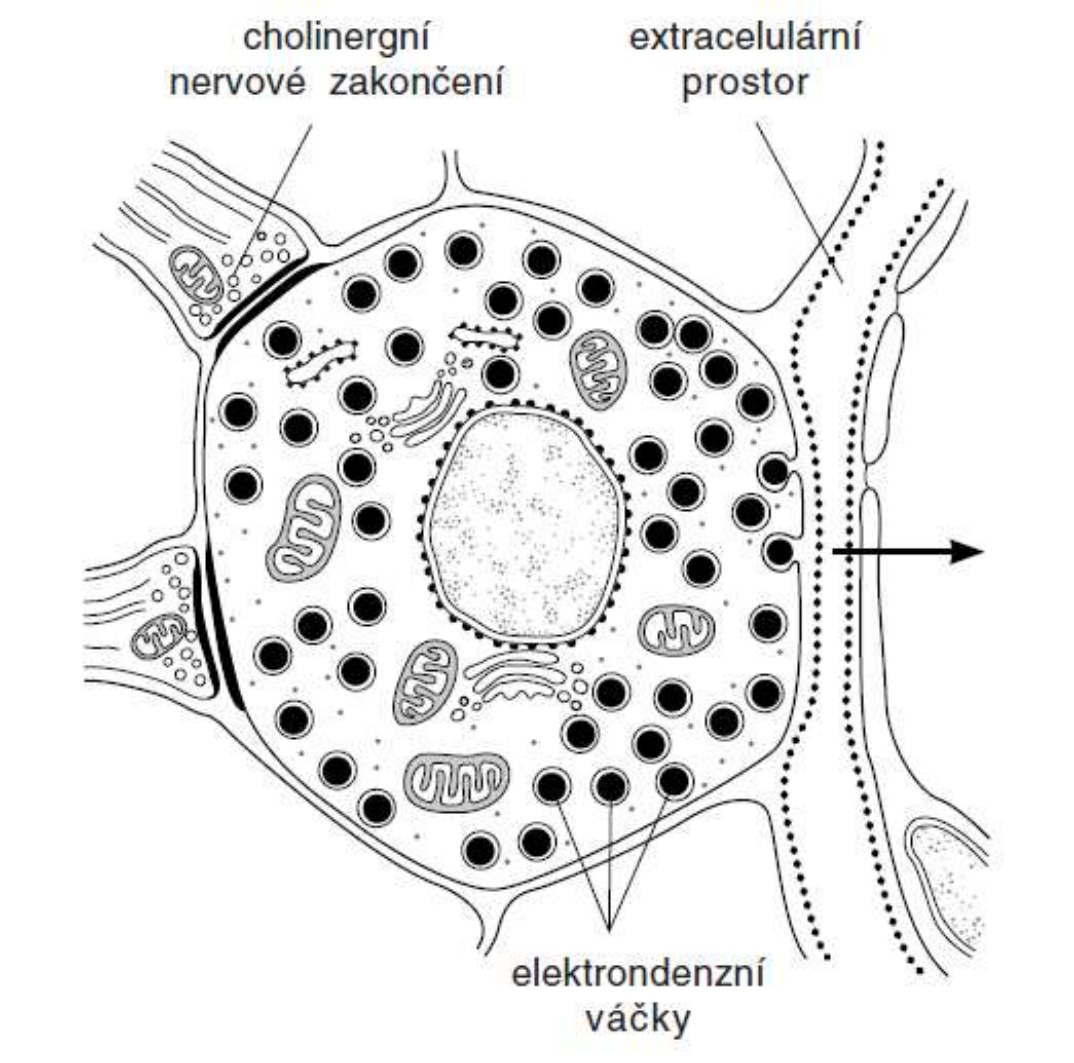
Noradrenaline secerning cells
(10 %)

Dopamine secerning cells
(?)

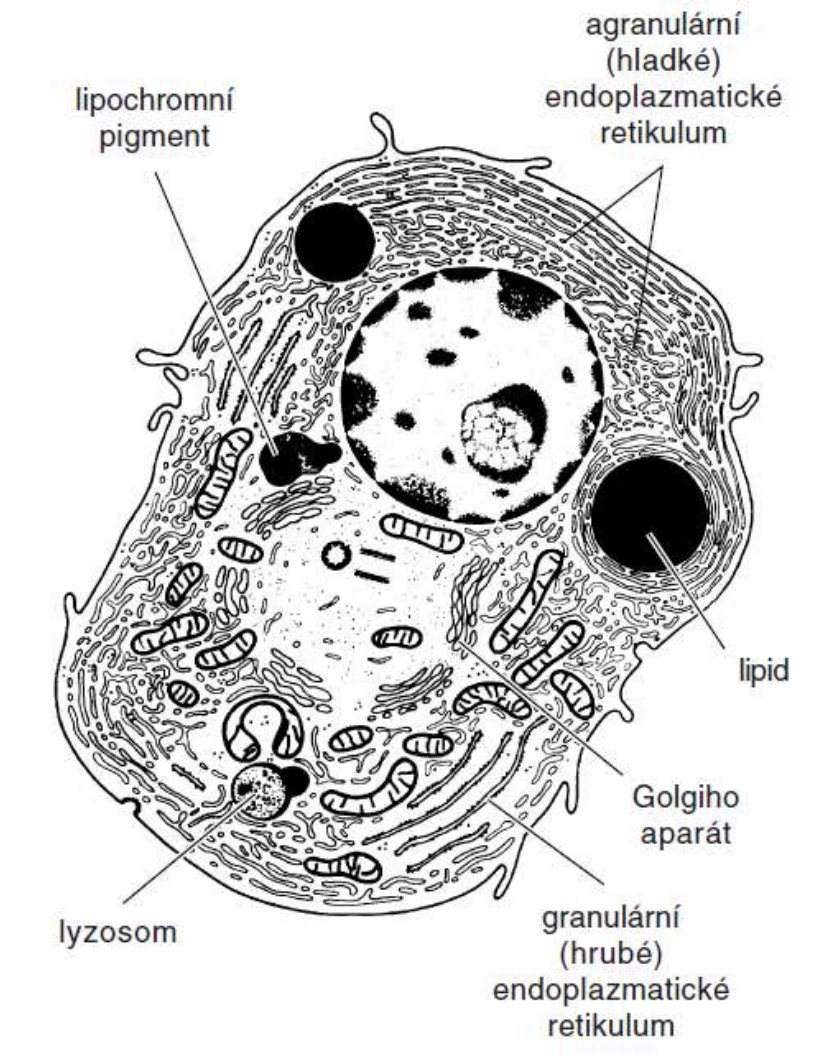


Secretory vesicles contain apart from catecholamines also ATP, neuropeptides – adrenomedullin, ACTH, VIP, calcium, magnesium and chromogranines.

Medulla - NA




Cortex



# Adrenal medulla

Preganglionic sympathetic neurones

↓

acetylcholine

↓

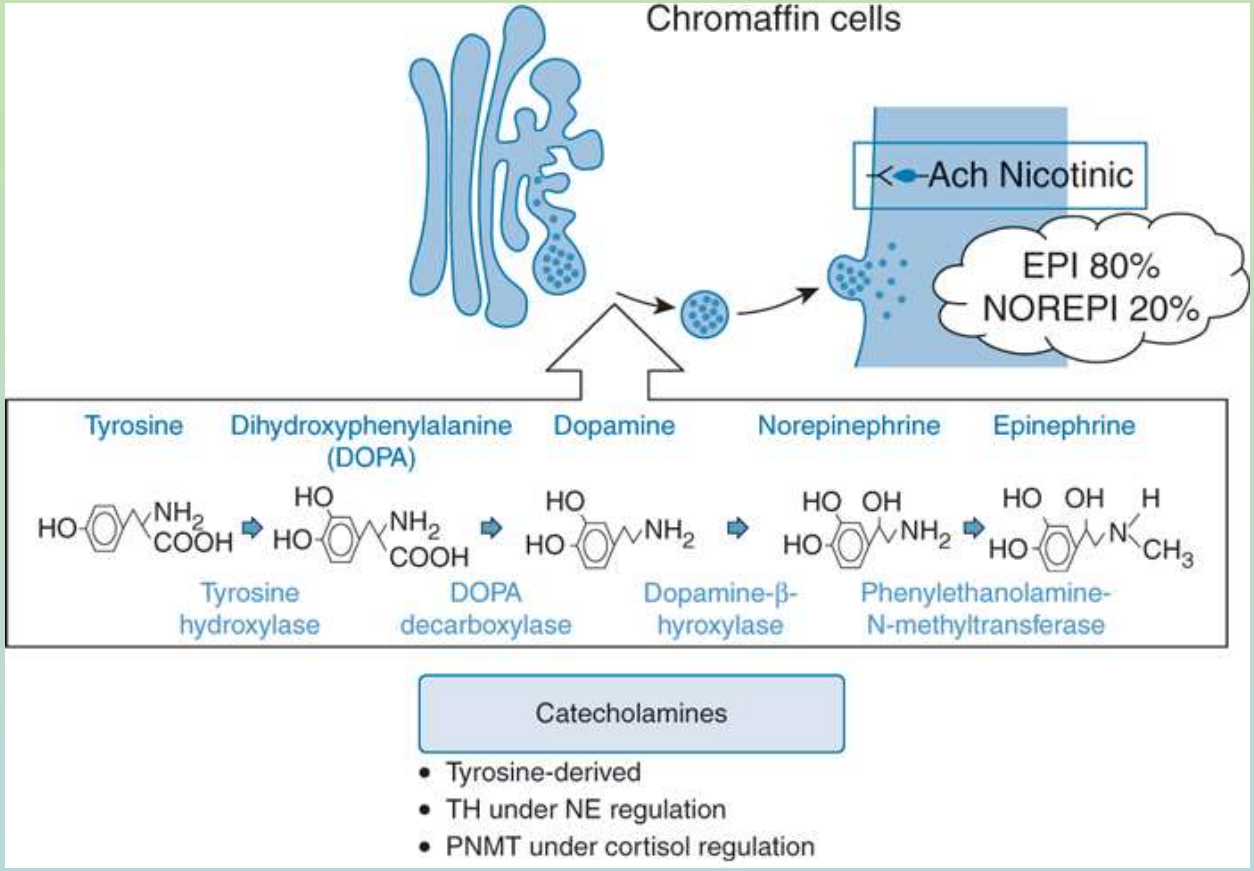
Sympathetic nervous ganglion – medulla

↓

Cholinergic receptors of chromaffin cells (feochromocytes)

↓

Catecholamines release




**Catecholamine synthesis is regulated by negative feedback loop through effect of noradrenaline.**

**Adrenaline synthesis is influences by steroid hormone production in adrenal cortex.**

**Noradrenaline conversion takes place in cytoplasm. It is then transported into vesicles by ATP-controlled transport (monoamine transporter VMAT1).**

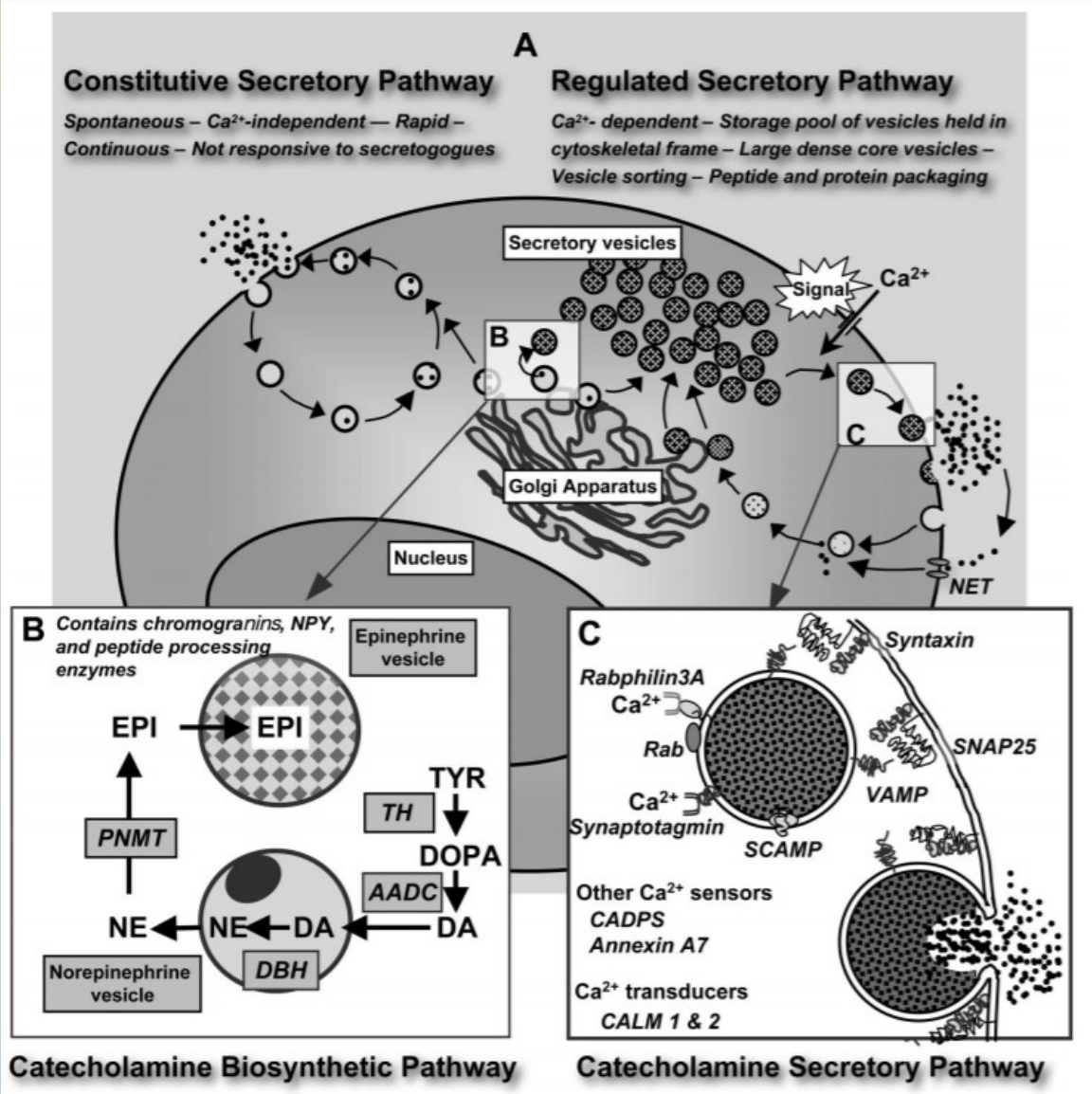
# Catecholamines secretion

Is determined by direct sympathetic stimulation:

1. Binding of Ach on nicotinic cholinergic receptors (ligand-gated ion channels)
2. Rapid $Na^+$ influx and depolarization
3. Activation of voltage-gated $Ca^{2+}$ ion channels
4. Influx of $Ca^{2+}$ ions
5. Secretory vesicles associated with voltage-gated $Ca^{2+}$ ion channels
6. Exocytosis – intersticium
7. Modulation of NA release by NA itself through $\alpha$2-AR (inhibition)
8. Transport to target organs

Constitutive secretion
- Spontaneous
- $Ca^{2+}$ independent

Regulated secretion
- $Ca^{2+}$ dependent
- Complex system of sorting and „packaging“

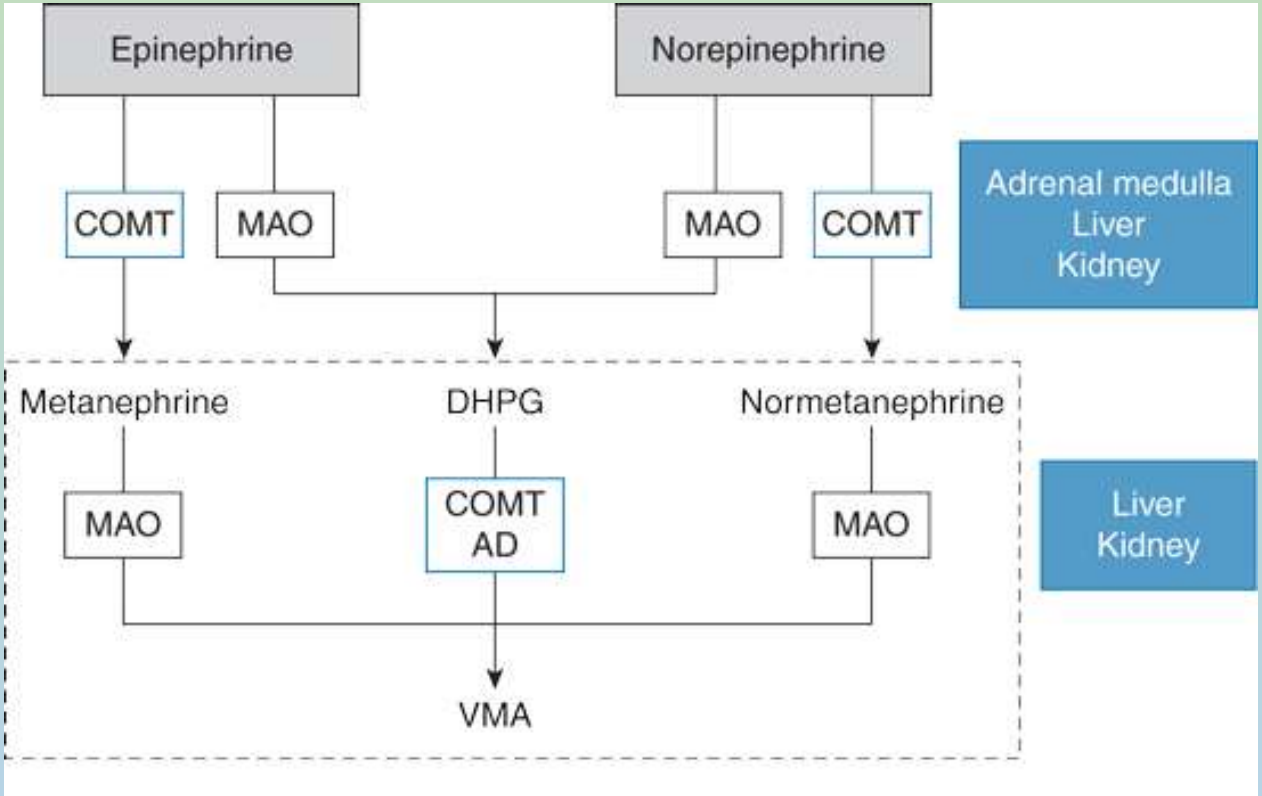


# Transport and metabolization of catecholamines

- Very short half-life in circulation (cca 2 min)
- Binds to albumin (50 %) with very low affinity
- Reuptake (up to 90 % - nerve endings, 10 % uptake extraneuronal tissues) and degradation

- Catechol-O-methyltransferase (COMT) – metadrenaline, normetadrenaline
- Monoaminooxidase (MAO) – deamination
- Aldehyde dehydrogenase
- Direct filtration (kidneys)

- Final degradation product is vanillylmandelic acid (A, NA) and homovanillic acid (DOP)



# Physiological effects of catecholamines

| Adrenergic receptor | G protein | Secondary messenger | Ligand |
|---|---|---|---|
| α1-adrenergic<br>α1A, α1B, α1D | Mainly $G_{Q/11}$ | Activation of PLCα, PKC, increased concentration of intracellular $Ca^{2+}$ ions | Noradrenaline > adrenaline >> (isoprenaline) |
| α2-adrenergic<br>α2A, α2B, α2C | Mainly $G\alpha_i$ and $G_0$ | Decreased activity of AC (antagonistic effect to k β-AR). Activation of $K^+$ ICH, inhibition of $Ca^{2+}$ ICH. Activation of PLCβ or $PLA_2$. | adrenaline = noradrenaline >> isoprenalin |
| β1-adrenergic | $G\alpha_s$ | Activation of AC and increased cAMP concentration | Isoprenalin > adrenaline = noradrenaline |
| β2-adrenergic | $G\alpha_s$ | Activation of AC and increased cAMP concentration | Isoprenalin > adrenaline >> noradrenaline |
| β3-adrenergic | $G\alpha_s$ | Activation of AC and increased cAMP concentration | Isoprenalin = noradrenaline > adrenaline |
| D1 family<br>D1, D5 | $G\alpha_s$<br>$G_{Olf}$ | Activation of AC and increased cAMP concentration | dopamine |
| D2 family<br>D2, D3, D4 | $G\alpha_i$ | Inhibition of AC and decreased cAMP concentration | dopamine |

Physiological effects of catecholamines are mediated through G-protein-coupled adrenergic receptors. Catecholamines from adrenal medulla cannot cross HEB and affect peripherial tissues.

# Main effects of catecholamines - overview

Clinical relevance

- Antagonistic effect of various α2AR subtypes
  - A – decresed blood pressure
  - B – increased blood pressure (vasoconstriction)
- Wide use of agonists and antagonists in clinical practice:
  - Cardiology
  - Ophthalmology
  - Internal medicine

| Mediated by α-AR | Mediated by β-AR |
|---|---|
| Vasoconstriction | Vasodilatation |
| (+) inotropy | (+) chronotropy |
| Smooth muscle relaxation (GIT) | (+) dromotropy |
| Sphincter contraction (GIT) | (+) inotropy |
| Mydriasis | Smooth muscle relaxation (GIT) |
| Stimulation of saliva and tear secretion | Musculus detrusor relaxation |
| Bronchoconstriction | Bronchodilatation |
| Ejaculation | Calorigenesis, thermogenesis |
| Gluconeogenesis (liver) | Glycogenolysis |
| (-) insulin secretion | Lipolysis |
| Thrombocytes aggregation | (+) renin secretion |
| (+) $Na^+$ reabsorption (kidneys) | (+) glucagon secretion |
| Pilomotor muscle contraction | Accommodation of distance vision |

# Physiological effects of catecholamines

Catecholamine secretion stimuli
- Sympathetic stimulation (generally)
- Stress response (physical, psychical stress)
- Bleeding and blood loss
- Hypoglycemia
- Trauma
- Surgery
- Fear
- **„fight or flight“**

**Acute response to stress stimuli**
- e.g. bronchodilatation, sphincter contraction, tachycardia, peripherial vasoconstriction and increased peripherial resistance, inhibition of motility (GIT)

**Ensuring energy requirements**
- Mobilisation of substrates – liver, muscles, adipose tissue
- Glycogenolysis, lipolysis
- Effect – increased glycemia, concentration of glycerol, FFA

Regulation of adrenergic receptors
- Chronic stimulation = changes in sensitivity (biological response) of target tissues
- **Desensitization of AR** (phosphorylation)
- **Internalization of AR**
- Upregulation:
  - Glucocorticoids
  - Thyroid hormones
  - Different upregulation of various AR receptors!

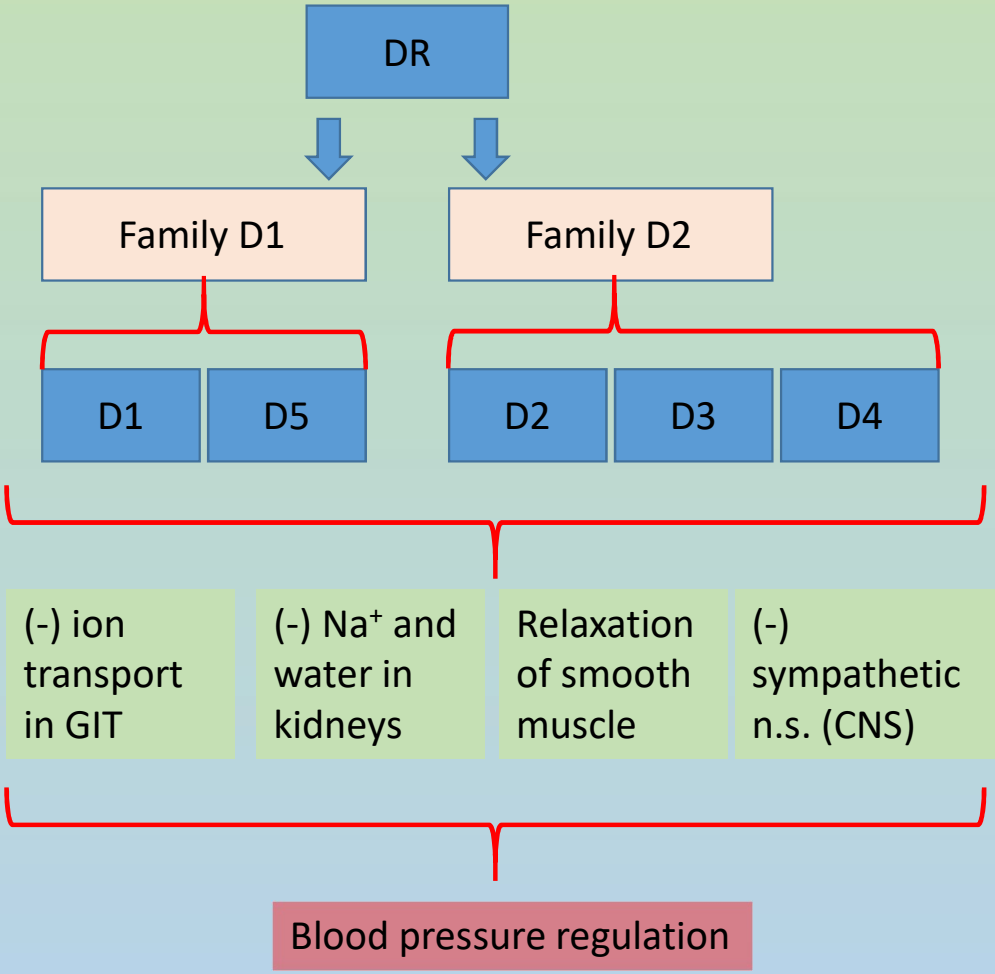
Biochemical aspects
- Monitoring of catecholamine secretion - urine

Clinical relevance
- Changes in target tissue sensitivity during chronic administration of agonists/antagonists
  - Chronic application of β-agonists – asthma
  - Chronic application of α-agonists – tachyphylaxis (intranasal decongestants)
- Feochromocytom

# Dopamine

Functions of dopamine outside of CNS :
- Hormone, paracrine and autocrine factor
- Cannot cross HEB!
- Regulation of ECF volume and ion balance
  - increased GFR
  - natriuretic effect
- Immune function
  - (-) lymphocyte activation
- Endocrine pancreas
  - (-) insulin secretion
- Heart
  - (+) inotropy
  - (+) systolic blood pressure
  - (0) diastolic blood pressure

Clinical relevance
- i.v. application in newborns
- Treatment of acute kidney damage?
- Cardiogenic shock
- Septic shock

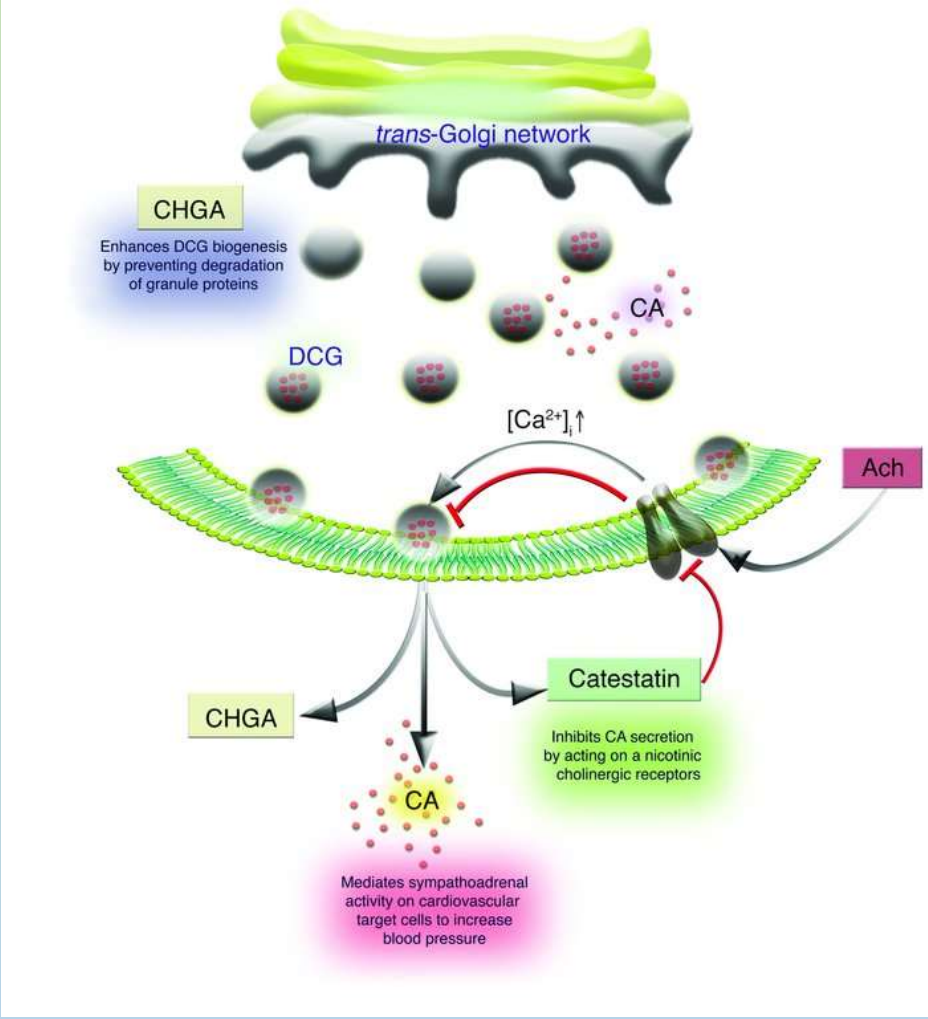


# Chromogranin A

Characteristics
- Acidic glycoprotein
- Precursor protein for:
  - Vasostatin-1
  - Vasostatin-2
  - Pancreastatin
  - Catestatin
  - Parastatin

  → eNOS
- Chromaffin cells of AM
- β-cells of pancreas
- Paraganglia
- ECL cells

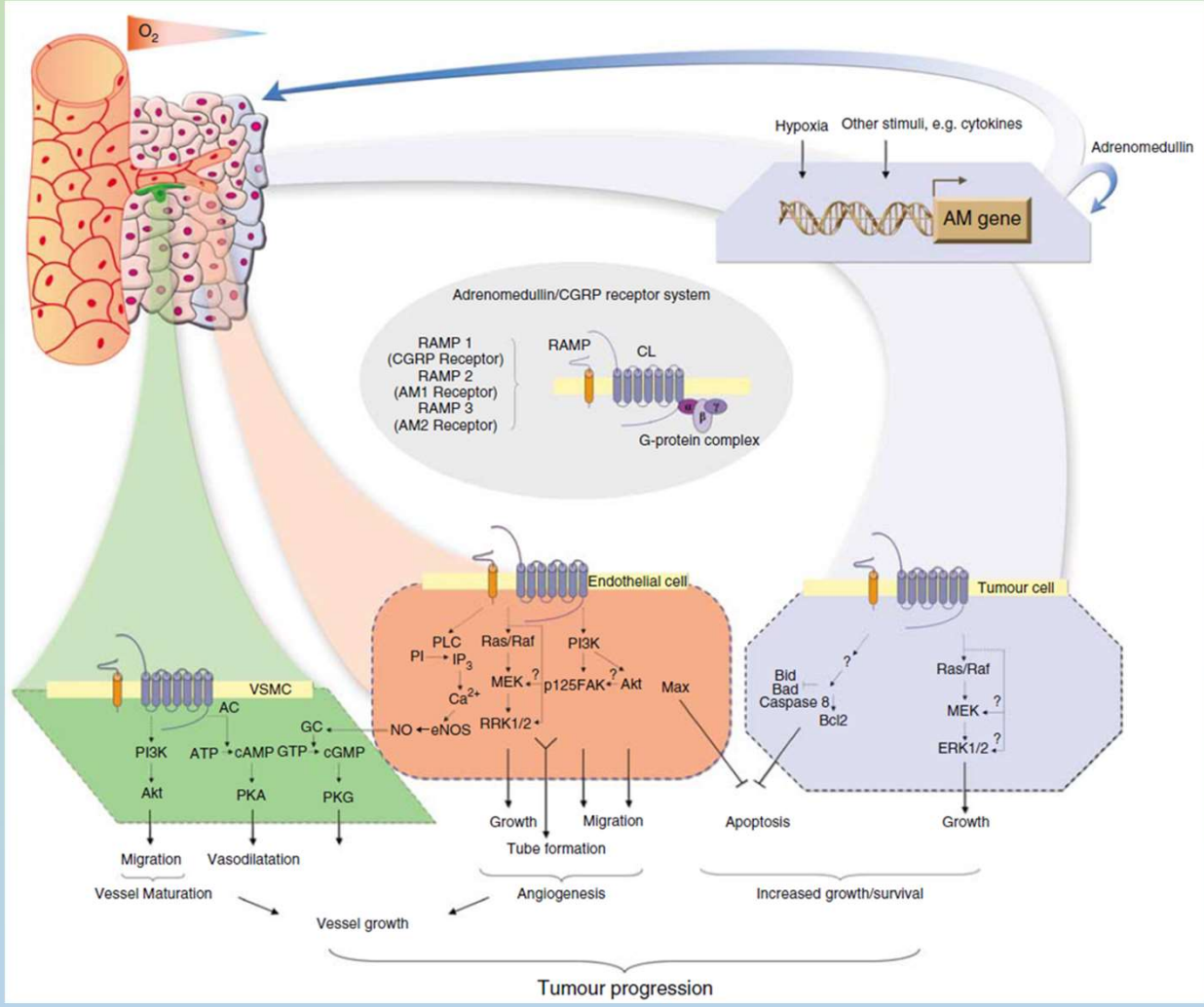
Functions and relevance
- Cardioprotective effect (catecholamines)
- Autoantigen – DM1
- Hormone secerning CgA - marker



# Adrenomedullin - AMD

Characteristics
- Hormone, neuromodulator, neurotransmitter
- Peptide (partial homology with CGRP)
- Receptors – combination of CALCR + RAMP2/3 – AM1/2
- Found in:
  - CNS
  - Blood vessels
  - Myocardium
  - Tumour tissue

Functions
- Vasodilatation (cAMP, NO)
- Cardioprotection
- Protection during oxidative stress
- Protection from hypoxic damage - angiogenesis



# Hormones of adrenal cortex

Hormones of adrenal cortex = cholesterol derivates

- C21 steroids with two carbon chain in position C17
  - Mineralocorticoids
  - Glucocorticoids
- C19 steroids with keto- or hydroxyl group in position C17
  - Androgens
- C18 steroids with 17-keto or hydroxyl group without angular methyl group in position C10

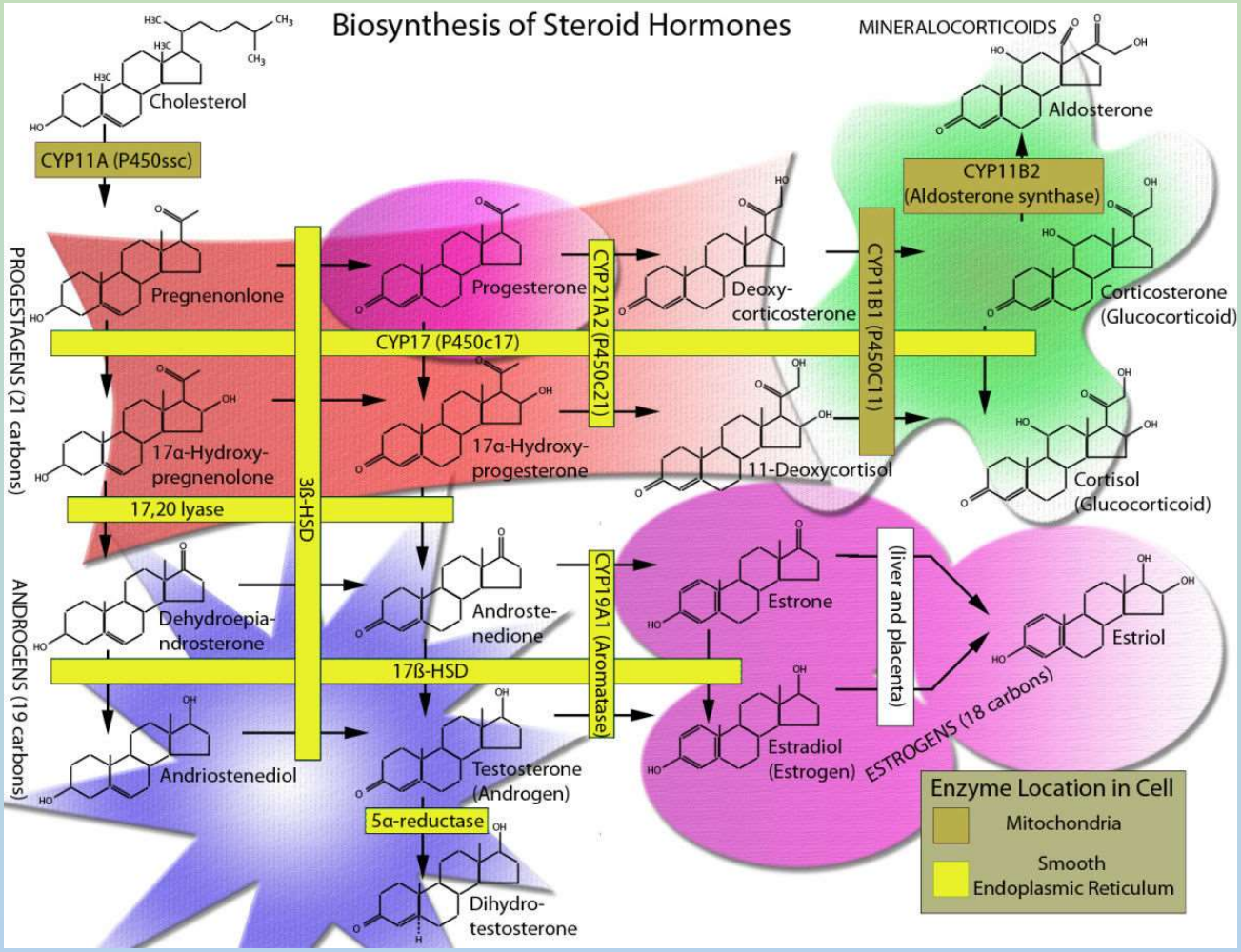
STAR (Steroid Acute Regulatory) proteins

- Transfer of cholesterol into inner mitochondrial membrane

Regulation of synthesis

- Acute (minutes) versus chronic

Source of cholesterol – cholesterol esters or plasma membrane



# Synthesis and secretion of steroid hormones

Glucocorticoids - pulsatile character under ACTH stimulation (cortisol – 10 – 20 mg/day)

Mineralocorticoids – ACTH only basal secretion, RAAS – angiotensin II (aldosterone – 100 – 150 μg/day)

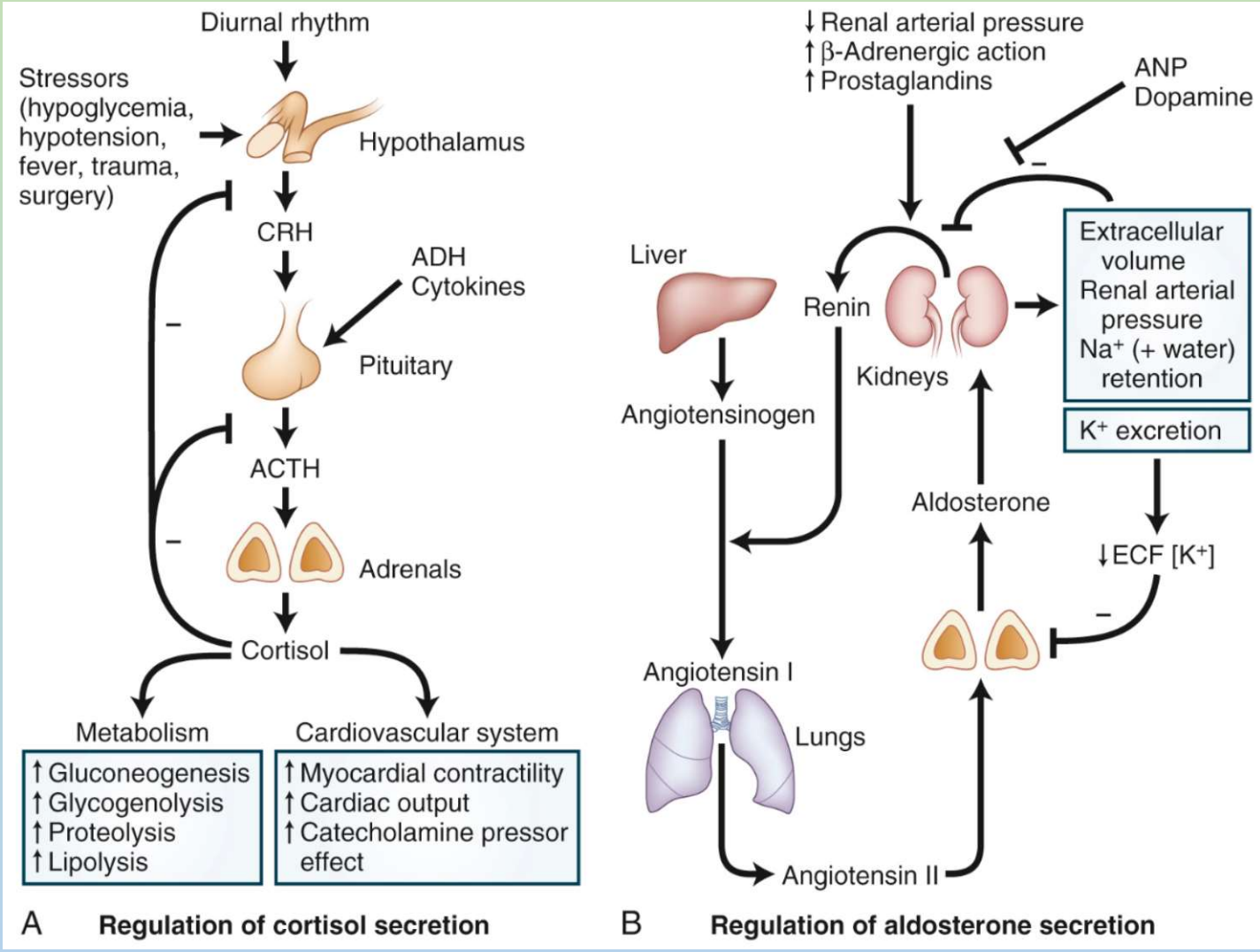
Androgens – ACTH (DHEA, DHEAS, androstenedione – 100 – 150 μg/day)

**Different expressions of enzymes catalyzing steps in steroid conversions are responsible for synthesis of various steroid hormones in individual zones of adrenal cortex.**

# Regulation of synthesis and secretion

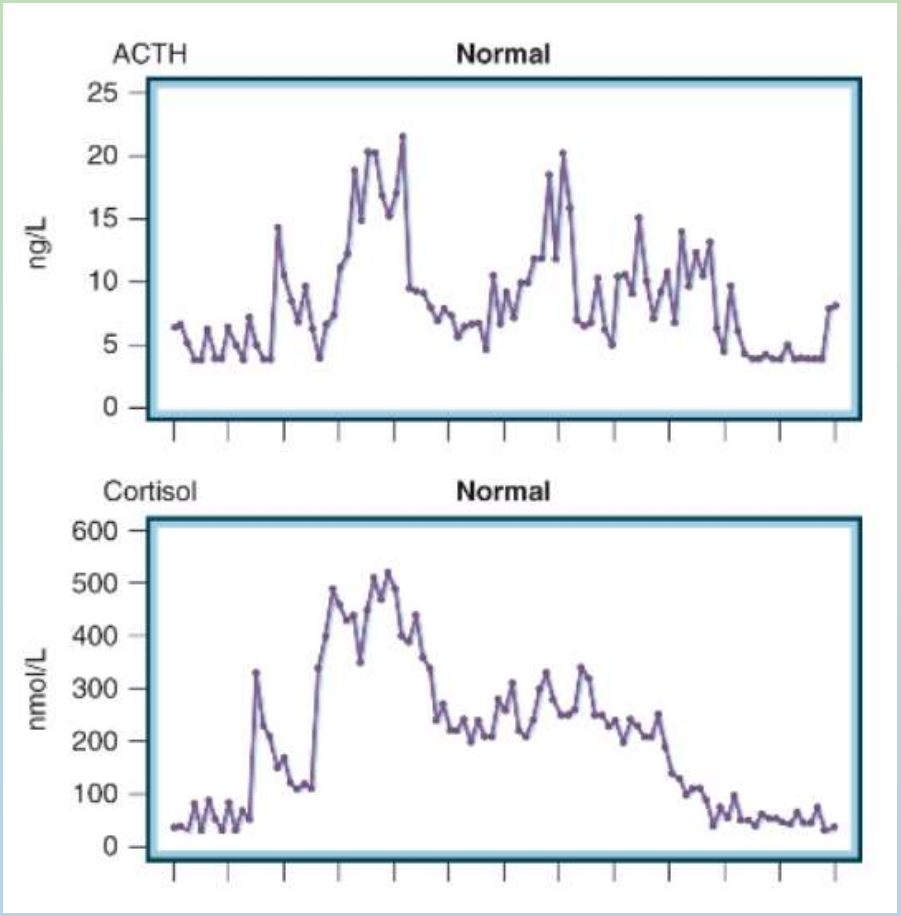
Glucocorticoids
- ACTH – $G\alpha_s$ – activation of AC and PAK
- Phosphorylation of cholesterol ester hydrolase
- Increased availability of cholesterol
- Increased STAR synthesis

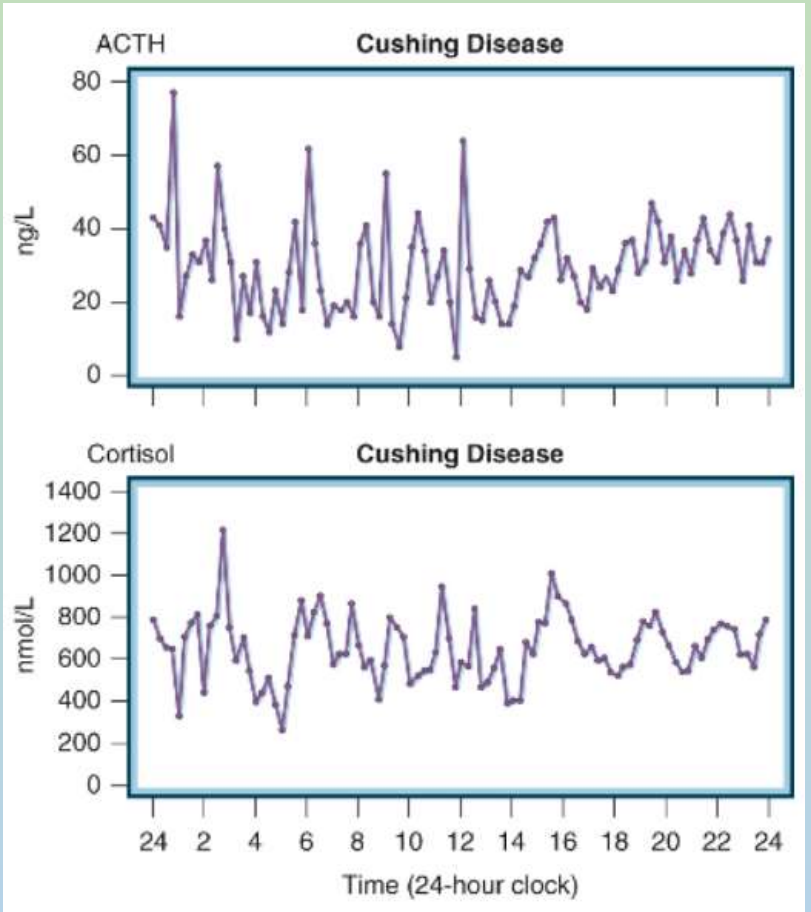
Mineralocorticoids
- Angiotensin II and extracellular $K^+$
- ACTH (only basal and acute secretion)
- RAAS system
  - Renin (juxtaglomerular cells)
  - Conversion of angiotensinogen
  - Angiotensin II stimulates aldosteron synthesis and secretion
- Inhibition also by somatostatin and dopamine



# Circadian and pulsatile secretion of ACTH and cortisol

Maximum in early morning



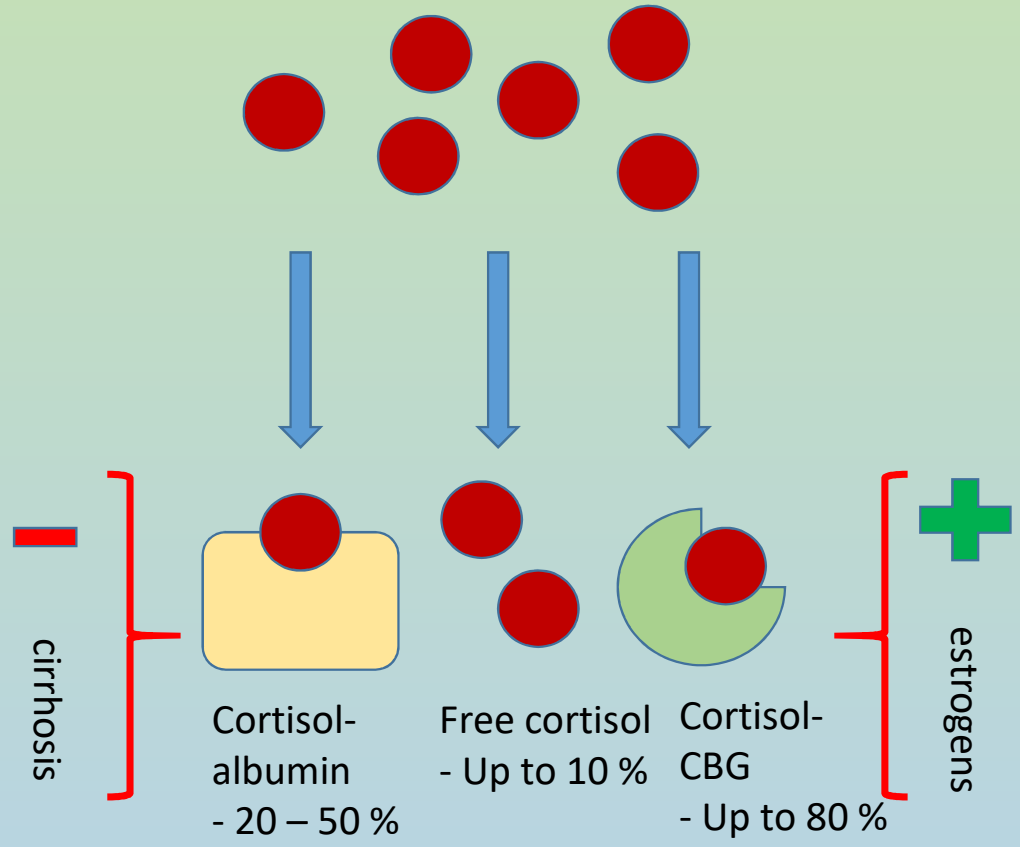

Increased frequency and amplitude of pulses, loss of circadian secretion

# Glucocorticoid metabolism

- Lipophilic
  - Conjugates
  - Binding to CBG proteins (transcortin, cortisol-binding globulin) and albumin
- Half-life 70 – 90 min

Detoxication
- Liver
- Kidney
- Reduction, oxidation, hydroxylation and conjugation
- Glucuronides and sulphates

Local glucocorticoid metabolism
- Tissues with different expression of isoforms of 11β-hydroxysteroid dehydrogenase type I (conversion cortisone to cortisol)
  - Liver, adipose tissue, lungs, skeletal muscle, smooth muscles of blood vessels, gonads, CNS
- Tissues with different expression of isoforms of 11β-hydroxysteroid dehydrogenase type II
  - Tubular system



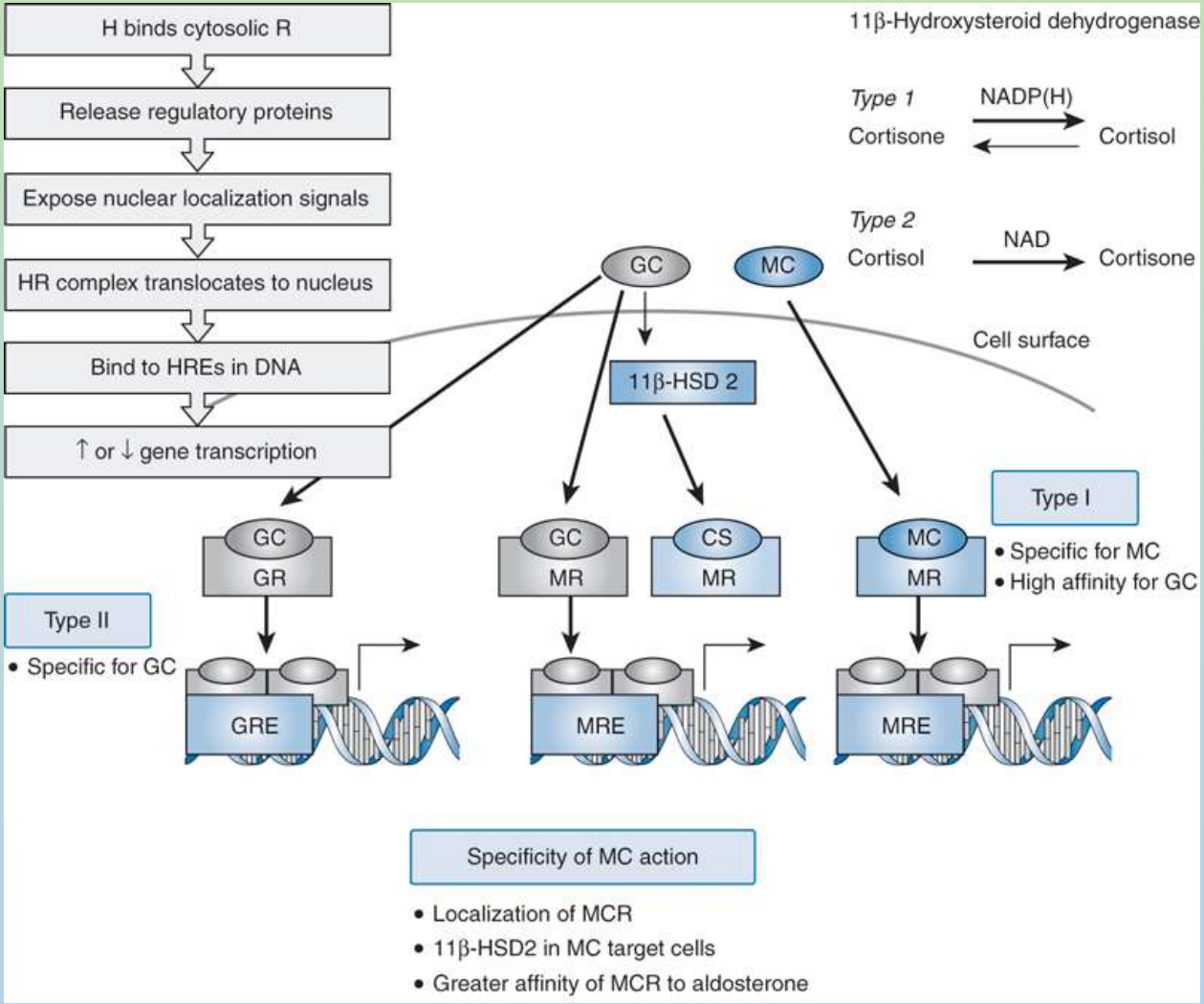

**Conversion of cortisol to cortisone is essential for prevention of cortisol binding to mineralocorticoid receptor.**

# Effects of glucocorticoids

1. Binding of GC on corresponding receptor
2. Conformational change and dissociation of receptor from complex HSP70 and HSP90
3. Migration to nucleus
4. Binding on GRE together with activating protein (AP1)

Glucocorticoids affect intermedial metabolism, stimulate proteolysis and gluconeogenesis, inhibit proteosynthesis (mainly in muscles) and stimulate mobilization of FFAs.

**All tissues express glucocorticoid receptors, which causes their wide array of effects.**



# Specific effects of glucocorticoids

| System | Induced gene expression | Suppressed gene expression |
|---|---|---|
| Immune system | Inhibitor of NF-κB, haptoglobin, TCR, p21, p27, p57, lipocortin | Interleukins, TNF-α, interferon-γ, E-selectin, COX-2, iNOS |
| Metabolism | PPAR-γ, glutamine synthase, glycogen synthase, Glu-6-phosphatase, leptin, γ-fibrinogen, cholesterol 7α-hydroxylase | Tryptophan hydroxylase, metalloproteases |
| Bone tissue | Androgen receptor (AR), calcitonin receptor (CTR), alcalic phosphatase, IGFBP6 | Osteocalcin, collagenase |
| Ion channels and transporters | ENaC-α, -β a –γ, SGK, aquaporin 1 | |
| Endocrine system | Basic FGF, VIP, endothelin, RXR, GHRH receptor, receptors for natriuretic peptides | GCR, prolactin, POMC/CRH, PTHrP, ADH |
| Growth and development | Surfactant proteins A, B, C | Fibronectin, α-fetoprotein, NGF, erythropoietin, G1 cyclins and CDKs |

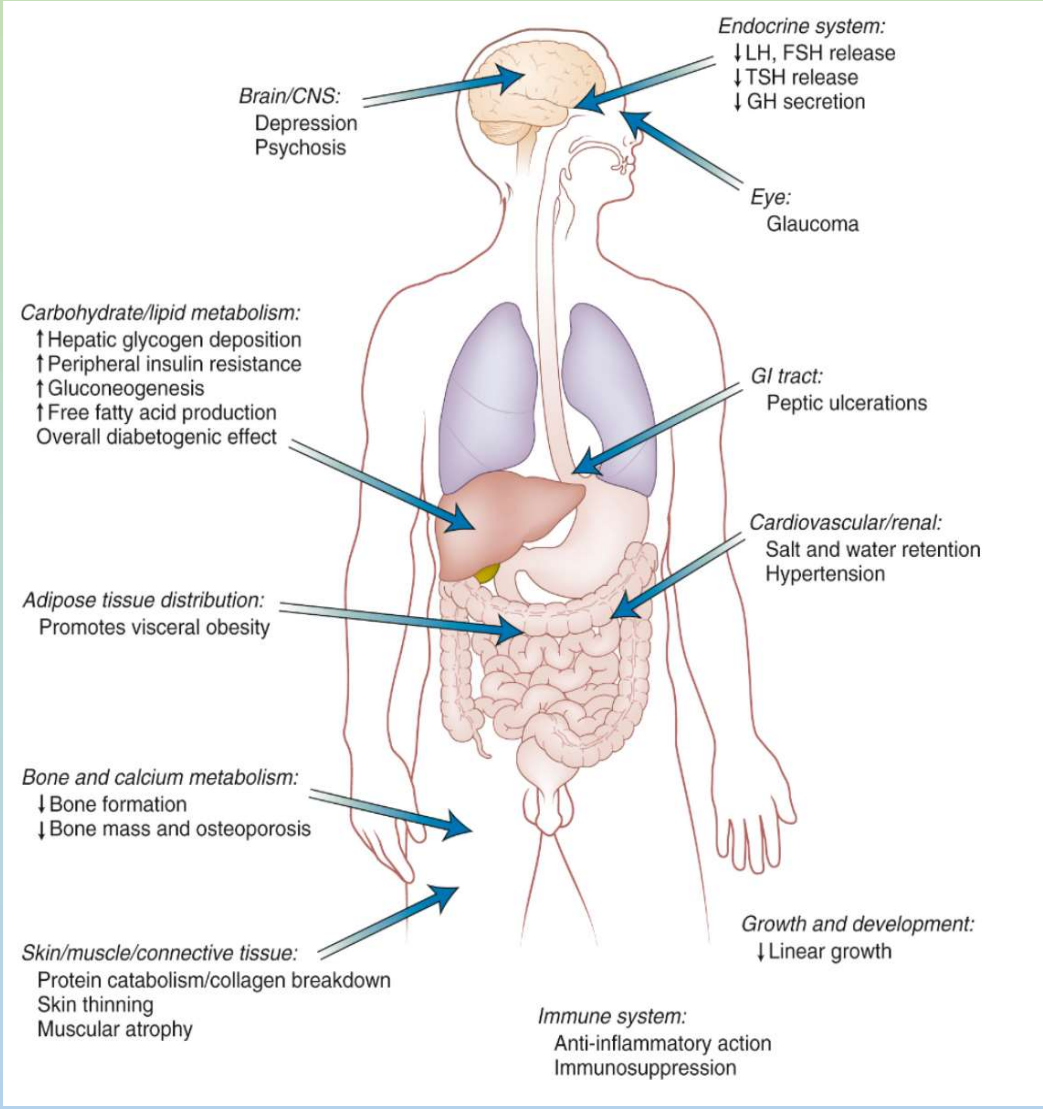
# Effects of glucocorticoids - overview

Cardiovascular system:
- Increased sensitivity to catecholamines ($\alpha$2-AR)
- Increased sensitivity to angiotensin II
- Inhibition of NO-mediated vasodilatation
- Stimulation of angiotensinogen synthesis
- HSD11B2-activity-dependent increase in $Na^+$ retention in distal tubulus and increased $K^+$ excretion
- Increased GFR
- Increased resorption of $Na^+$ in proximal tubulus

Increased blood pressure

Immune system:
- Decrease in lymphocyte count (T more than B) based on redistribution to spleen, lymphatic nodes and bone marrow
- Increased number of neutrophils
- Decreased number of eosinophils and basophils
- Inhibition of monocyte-macrophage differentation
- Inhibition of immunoglobulin synthesis
- Inhibition of cytokine synthesis
- Inhibition of histamine and serotonin secretion from mast cells
- Inhibition of prostaglandine synthesis

Anti-inflammatory and immunosuppressive effect



# Glucocorticoids – clinical aspects

| Field | Utilization |
|---|---|
| Endocrinology | Substitution therapy |
| Dermatology | Dermatitis |
| Haematology, hematooncology | Leukemia, lymphoma, haemolytic anemia, immune thrombocytopenic purpura |
| Gastroenterology | Ulcerative colitis, Crohn's disease |
| Internal medicine, Infectious diseases | Chronic active hepatitis, transplantation, nephrotic syndrome, vasculitis |
| Neurology | Cerebral edema, increased intracranial pressure |
| Pneumology | Asthma, angioedema, anaphylaxis, sarcoidosis, obstructive pulmonary diseases |
| Rheumatology | Systemic lupus erythematosus, arteritis, rheumatoid arthritis |

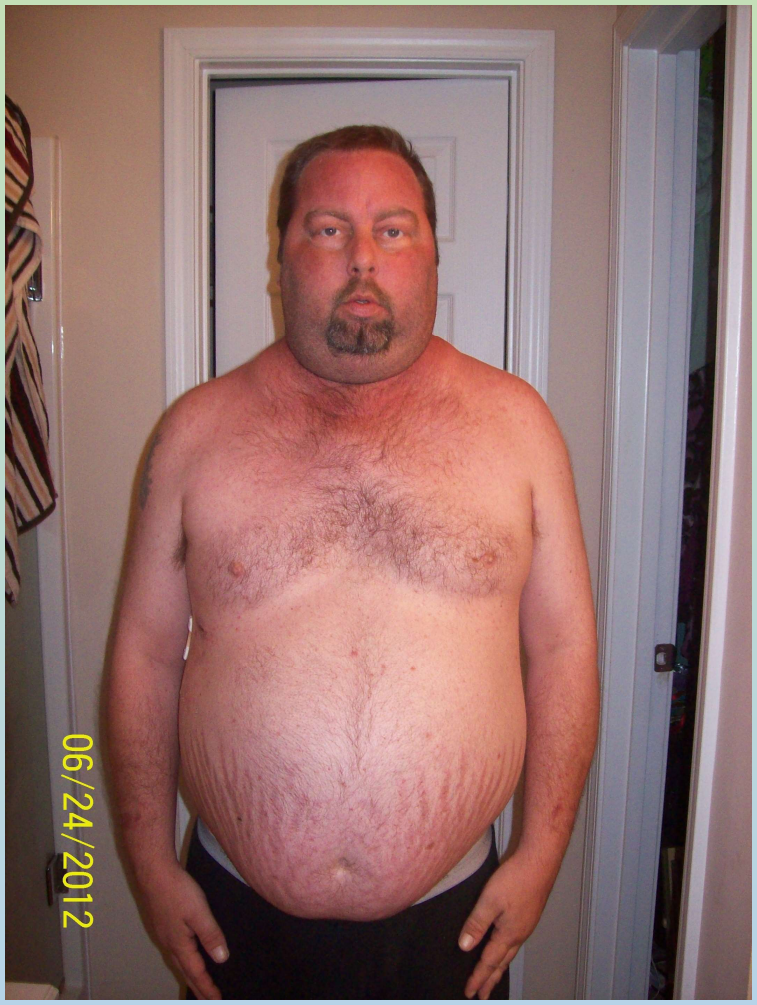
Long-term glucocorticoid application:

- Steroid diabetes
- Secondary osteoporosis

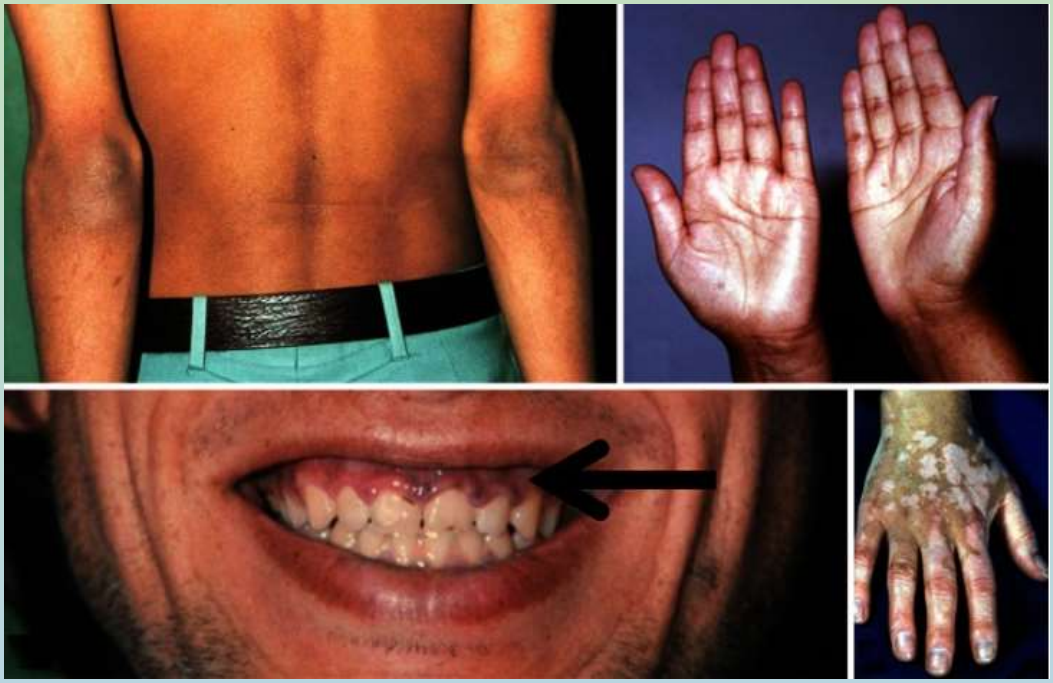
- Dexamethasone test
- Metyrapone test
- CRH stimulation test

**Glucocorticoids are characteristic by not only glucocorticoid, but also mineralocorticoid activity and by ability to affect axis CRH-ACTH-GC by feedback loop.**

# Glucocorticoids – clinical aspects

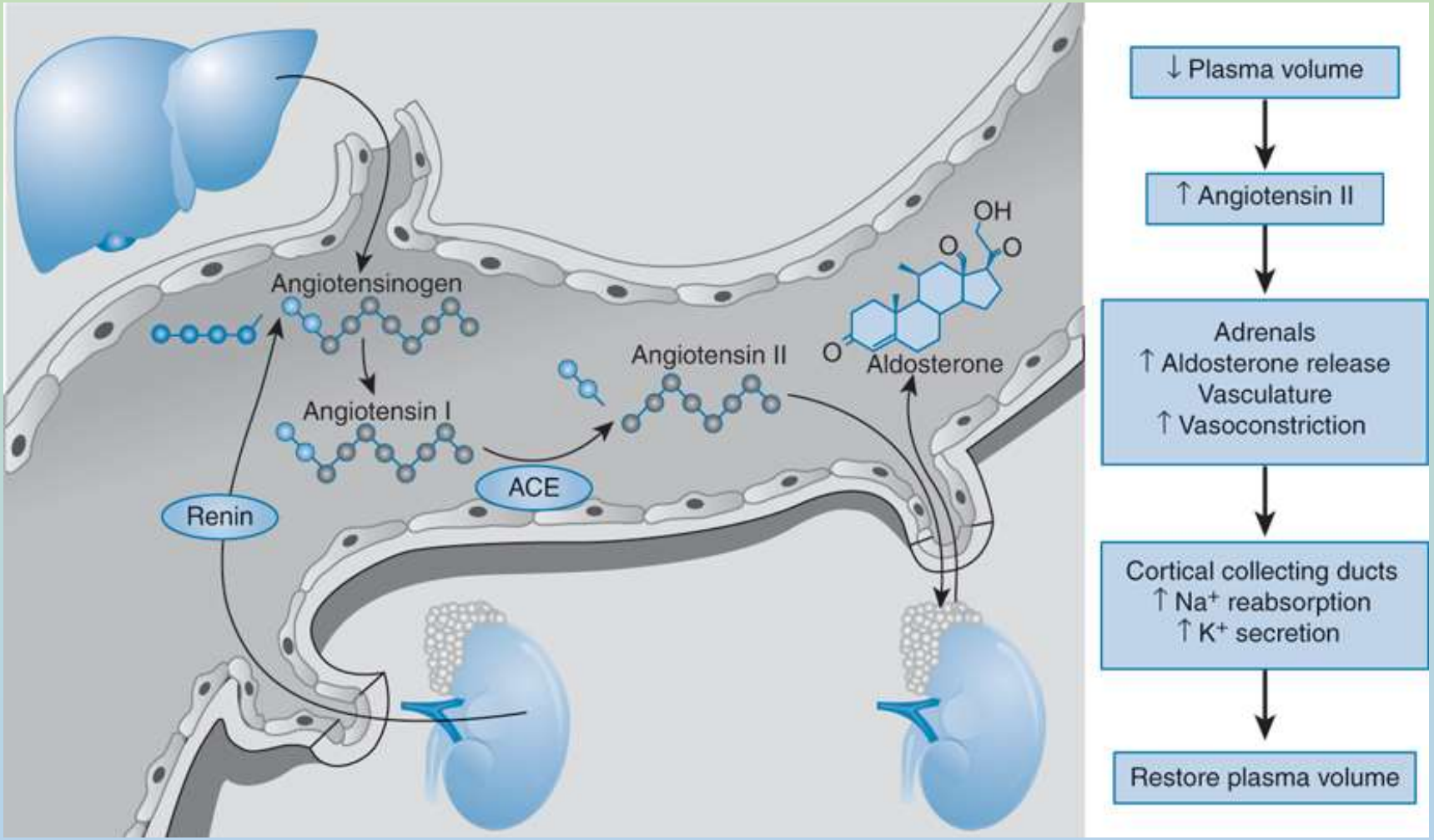



Cushing syndrom



Addison disease

# Mineralocorticoids – regulation of aldosteron secretion

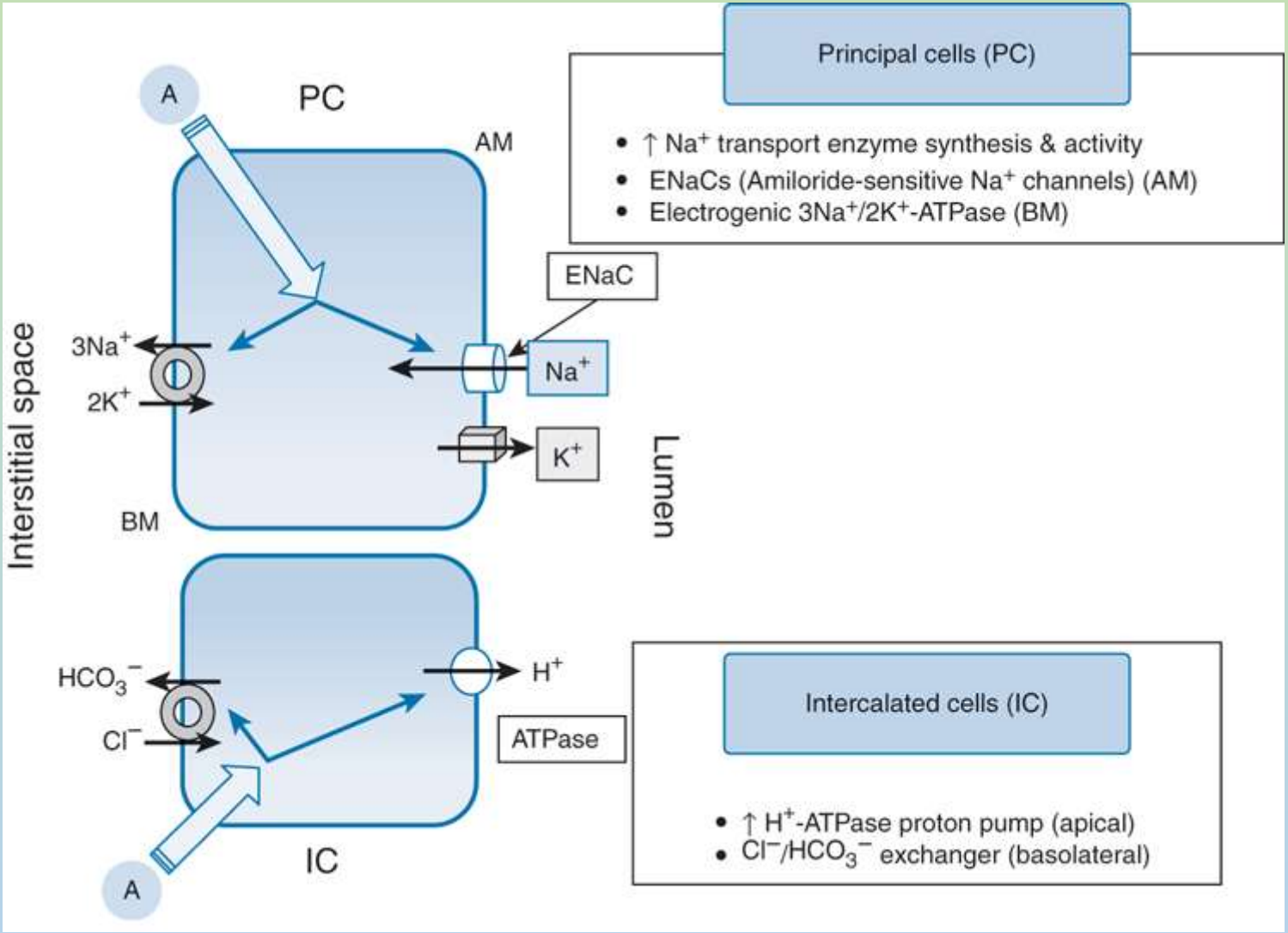


# Effects of mineralocorticoids

Receptors
- Limited distribution
- Keratinocytes
- Neurons (CNS)
- Myocytes
- Smooth muscle cells in large blood vessels

Main effects of aldosterone
- Stimulation of epithelial Na transport
  - Distal tubulus and collecting duct
  - Distal colon
  - Salivary glands

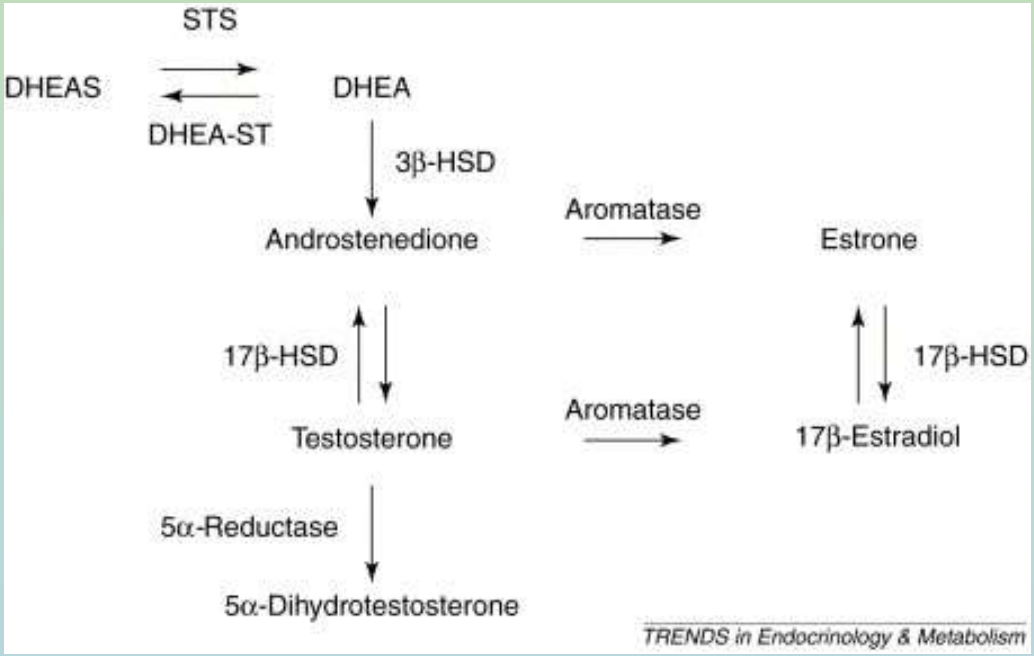
Mechanism of effect
- (+) synthesis of $Na^+$ IK
- (+) synthesis of $Na^+/K^+$-ATPase
- (+) activity of $Na^+/K^+$-ATPase
- (+) synthesis of $H^+$-ATPase
- (+) synthesis of $Cl^-/HCO_3^-$ exchanger



# Adrenal gland androgens

- DHEA is important precursor for sex hormones synthesis
- Conversion by enzymes from β-hydroxysteroid dehydrogenase group and aromatase in **peripherial tissues**
- Possible presence of CASH (cortical androgen-stimulating hormone)

Possible functions of adrenal gland androgens
- Libido and its „regulation“
- Cardioprotective effects in men
- Possible protective role from ovarial and breast carcinoms in premenopausal women
- Neuroprotection
- Effect on synthesis and secretion:
  - IGF-1
  - Testosterone and dihydrotestosterone
  - Estradiol




**Androgens produced in adrenal glands represent more than 50 % of circulating androgens in premenopausal women. In men dominates the testicular production.**

# Clinical aspects

- **Congenital adrenal hyperplasia** (CAH)
  - prenatal virilization (high androgen concentration *in utero*)
  - Deficit of 21β-hydroxylase, „salt wasting form“
  - Deficit of 11β-hydroxylase, „hypertensive form“
  - Deficit of 3β-hydroxysteroid dehydrogenase II
  - Deficit of 17α-hydroxylase
- **Congenital lipoid adrenal hyperplasia**
  - Defective conversion of cholesterol to pregnenolone
- **Adrenogenital syndrome**
- **Hyperaldosteronism**
  - Primary hyperaldosteronism
  - Secondary hyperaldosteronism with increased renin level
- **Secondary adrenal insufficiency** (ACTH)
- **Tertiary adrenal insufficiency** (CRH)
- **Hyporeninemic hypoaldosteronism**
- **Pseudohypoaldosteronism**

Apparent mineralocorticoid excess syndrome
- Inhibition or absence of 11β-hydroxysteroid dehydrogenase II

**Watch out for liquorice ☺**