Homeostasis

CHAPTER 14

↳ Definition ⇒ Maintenance of constant internal environment in an organism

PHYSIOLOGICAL FACTORS CONTROLLED

- core body temp
- metabolic wastes (eg. CO_2, urea)
- blood pH / glucose
- Ψ of blood
- conc. of O_2 / CO_2 in blood

INTERNAL ENVIRONMENT

- for cells = tissue fluid
  - ↳ cell's immediate environment
- TEMPERATURE
  - temp ↓ = metabolic reactions ↓
  - temp ↑ = proteins & enzymes denatured
- WATER POTENTIAL
  - Ψ ↓ = H_2O moves out of cells ∴ metabolic reactions stop / slow down
  - Ψ ↑ = H_2O enters cell ∴ swell / burst
- GLUCOSE CONC
  - ↓ = respiration slow / stop ∴ energy ↓
  - ↑ = H_2O moves out of cells

HOMEOSTATIC CONTROL

- 3 interdependent components :
  - receptor, control center, effector
- use negative feedback control loop:
- Receptor senses environmental stimuli.
- sends information through nervous system to a central control (in brain / spinal cord.) → input
  - ↳ aka control centre
- uses :
  - → nervous
  - → endocrine system

(2 coordination systems)

- Control centre signals an effector to carry out an action → output.
- These actions → corrective actions
  - ↳ to correct / reverse the change & bring it back to set point
- +ve feedback ⇒ enhances / accelerates output created by an activated stimulus
- -ve feedback ⇒ reduces the output or activity of any organ / system back to its normal range of functioning.

THERMOREGULATION

- control of body temperature.
- involves nervous & endocrine system
- mammals generate heat & retain it within their bodies (not dependent on environment)
- heat released during respiration, much produced by liver (energy requirement ↑)
  - heat produced absorbed by blood flowing through liver & distributed around rest of body.
- Hypothalamus → central control for body temp.
- Thermoreceptor cells in hypothalamus monitor temperature of blood as it passes through the brain.
- Hypothalamus also receives info from skin receptors (monitor external temperature.

RESPONSES TO TEMP CHANGE

EFFECTOR	TEMP ↓	TEMP ↑
Smooth muscles in arterioles in skin.	→ vasoconstriction → lumen of arterioles ↓ ∴ blood to capillaries ↓ ∴ less heat lost from blood	→ vasodilation → blood to capillaries ↑ ∴ heat loss ↑
Sweat glands	→ production of sweat ↓ ∴ heat loss by evaporation ↓	→ production of sweat ↑ → H_2O has high latent heat of vapourisation
Erector pili muscles in skin	→ contract, erecting skin hairs ∴ trapping an insulating layer of air next to the skin	→ muscles relax, lowering skin hairs, reducing insulation.
Skeletal muscles	→ involuntary contraction of skeletal muscles generates heat which is absorbed by blood & carried around the body	→ no shivering

Effector	TEMP ↓	TEMP ↑
Adrenal & Thyroid gland	→ Hypothalamus releases a hormone which activates the anterior pituitary gland to release thyroid stimulating hormone (TSH). → TSH stimulates thyroid gland to secrete thyroxine → Thyroxine ↑ metabolic rate	→ Hypothalamus reduces the release of TSH. → ∴ thyroxine ↓ from thyroid gland.
Behaviour	→ curling up → warm clothing etc.	→ resting w/ limbs spread out → air conditioning etc.

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EXCRETION

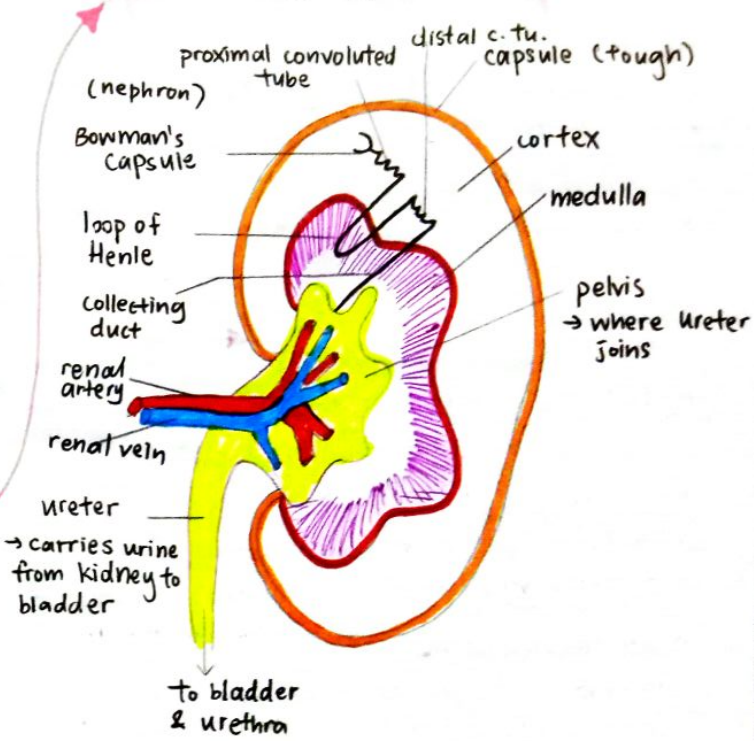
⇨ removal of unwanted products of metabolism.

→ major excretory products
- → CO_2
- → urea

→ **CO_2**
- → produced by aerobic respiration
- → CO_2 ↑, pH of blood ↓

→ **urea**
- → nitrogenous excretory product
- → produced in liver
- → other nitrogenous ex. pro. = creatinine, uric acid.

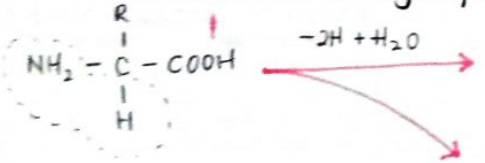
STRUCTURE OF THE KIDNEY



DEAMINATION

→ excess protein cannot be stored, but amino acids provide energy

→ ∴ liver removes amino groups ⇒ deamination

→ 

keto acid → respired / converted to glucose / fat

→ amino group & H removed → NH_3 ammonia

CO_2

$CO(NH_2)_2 + H_2O$ urea

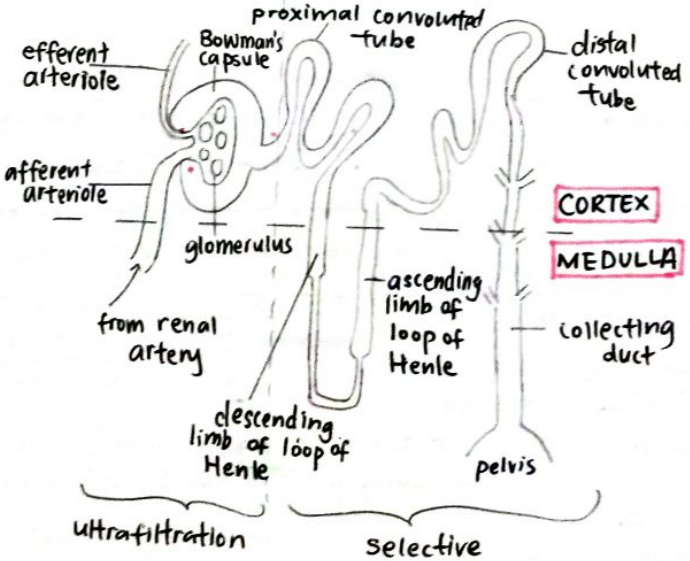
} urea cycle

→ Ammonia solubility ↑ & toxic ∴ NH_3 converted to urea

→ urea diffuses from liver cells into blood plasma.

→ As blood passes through the kidneys, urea is filtered & excreted.

STRUCTURE OF NEPHRON



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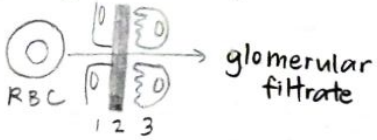
ULTRAFILTRATION

→ blood in glomerulus separated from lumen of Bowman's capsule by
- → endothelium
  ↳ one cell thick w/ pores (more than normal)
- → basement membrane
  ↳ made up of network of collagen & glycoproteins
- → podocytes (of Bowman's capsule inner lining)
  ↳ many finger-like projections w/ gaps between them



→ Blood in glomerulus is at a relatively high pressure. ∵ efferent arteriole is narrower than afferent arteriole. Ψ of blood plasma ↑. This forces molecules from blood into Bowman's capsule.

→ Pores in endothelium & slits between podocytes let all molecules through.

→ Basement membrane → filter.

→ RBC, WBC, plasma proteins cannot pass

→ ∴ glomerular filtrate = blood plasma w/out proteins

FACTORS AFFECTING GLOMERULAR FILTRATION RATE

→ Ψ in blood lower ∵
- → pressure ↑

→ But solutes in blood plasma ↑ than in glomerular filtrate. (Ψ ↑ in blood ? No. ↓

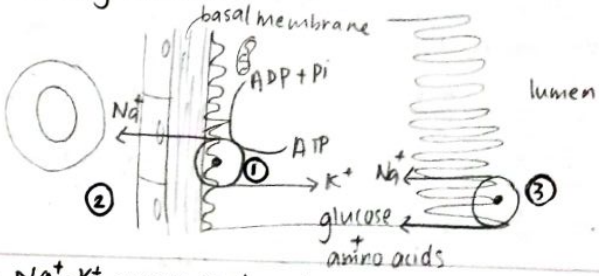
→ overall, effect of diff in pressure outweighs the effect of diff in solute conc.

REABSORPTION IN P.C.T.

→ Some substances of glomerulus filtrate need to be retained
- → H_2O
- → glucose
- → Na^+, Cl^-
- → vitamins & amino acids.

→ ∴ taken back into blood through walls of PCT → selective reabsorption

→ PCT made of single layer of cuboidal epithelial cells
- → microvilli to ↑ SA
- → tight junctions hold adjacent cells tgt
  ↳ so reabsorbed substances pass through cells.
- → many mitochondria to provide energy for Na^+-K^+ pump proteins in outer membranes.
- → co-transporter proteins in membrane facing lumen.



① → Na^+-K^+ pumps in basal membrane of PCT cells use ATP made by mitochondria.
- → $[Na^+]$ in cytoplasm ↓
- → basal membrane folded so SA ↑ for many Na^+K^+

② → blood plasma rapidly removes absorbed substances

③ → $[Na^+]$ in cyto ↓ ∴ Na^+ diffuse into PCT
- → Na^+ can only enter through co-transporter protein.
  ↳ brings in glucose / amino acid at same time
- → passive movement of Na^+ into cell provides energy to move glucose molecules even against conc. grad.
  ↳ secondary / indirect active transport

→ Reabsorbed:
- → all glucose
- → most Na^+, Cl^-
- → all amino acids & vitamins
- → most H_2O
  ↳ solutes in filtrate ↓ ∴ Ψ of filtrate ↑ than in blood ∴ H_2O enters blood
- → ½ of the urea (small & easily pass through

→ not reabsorbed:
- → uric acid
- → creatinine
  ↳ actively secreted out of cells

→ 64% of H_2O NOT reabsorbed & enters loop of Henle

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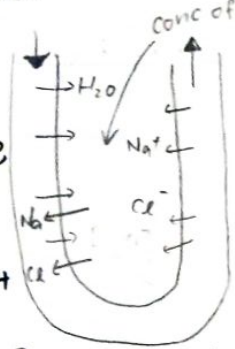
REABSORBTION IN LOOP OF HENLE

- Function ⇒ build up a high conc of Na^+ & Cl^- in tissues of medulla
  - ↳ allows highly conc. urine to be produced
- 

As fluid flows down descending limb, H_2O moves out by osmosis
NaCl in medulla ↑ so it diffuses in.
As it flows up ascending limb, Na^+ & Cl^- move out into tissues, first by diffusion, then by active transport.
By the time fluid reaches bottom, Ψ↓ than at top.
- This creates ↓Ψ in tissues of medulla.
- Descending limb permeable to H_2O & Na^+ Cl^-
- Ascending limb only permeable to Na^+, Cl^-, urea
- Two limbs running side by side with fluid flowing in opposite directions
  - ↳ enables max conc of solutes to build up inside & outside at bottom of loop
  - ↳ counter-current effect.
- Ascending loop & loop of Henle permeable to urea ∴ urea also conc. in medulla tissue
- Collect duct runs back down medulla, ∴ H_2O can move out until Ψ of urine same as medulla.
  - ↳ controlled by ADH
- Urea concentrated in tissue fluid in medulla

REABSORPTION IN DCT & CD

- Fluid lost H_2O & Na^+ in loop of Henle
- ∴ conc of urea ↑
- in DCT & CD Na^+ actively pumped out into tissue fluid
- K^+ actively transported into tubule
- H_2O moves out ∵ medulla Ψ ↓, ∴ conc. of urea ↑ more.
- urine formed.

OSMOREGULATION

- ↳ control of Ψ of body fluids
- osmoreceptors → specialised sensory neurones in hypothalamus
- when Ψ below set point, nerve impulses sent to posterior pituitary gland.
- ADH secreted
  - ↳ stimulates reabsorption of H_2O

EFFECTS OF ADH

- Acts on cell surface membranes of collecting ducts cells
- makes them more permeable to water.
- ADH molecules bind to receptor proteins on cell surface membranes.
- enzyme (phosphorylase) activated in the cell
- Cells contain ready-made vesicles surrounded by membrane containing aquaporins (water-permeable channels).
- Vesicles move to csm & fuse w/ it.
- permeability to H_2O ↑, ∴ H_2O can move through aquaporins out of tubule, into tissue fluid of medulla.
- volume of urine ↓, conc ↑
- when Ψ of blood ↑, osmoregulators not stimulated
- ADH not secreted.
- Aquaporins move out of csm back into cyto as part of vesicles
- permeability ↓, vol of urine ↑, conc ↓

CONTROL OF BLOOD GLUCOSE

- If glucose conc too low → not enough for respiration
- If glucose conc too high → effects Ψ
- Carried out by hormones secreted by endocrine tissue in pancreas
- The cells → islets of Langerhans

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- Islets
  - α cells - secrete glucagon
  - β cells - secrete insulin
- α & β cells → receptors & central control

HIGH BLOOD GLUCOSE

- Glucose can only enter cell through GLUT
- Muscle cells - GLUT4
- Brain cells - GLUT 1
- Liver cells - GLUT 2
- As blood flows through panoreas, α & β cells detect increase in glucose conc.
- α stop secreting glucagon, β secrete insulin
- Insulin receptors in liver, muscle, adipose
- Insulin stimulate cells to increase absorption rate of glucose from blood
  - ↳ convert glucose → glycogen.
- When insulin molecules bind to receptors on muscle cells, vesicles w/ GLUT 4 proteins move to csm & fuse → glucose enter cell
- Insulin activates enzyme glucokinase
  - ↳ phosphorylates glucose
  - ↳ traps glucose inside cells
- Insulin activates phosphofructokinase & glycogen synthase
  - ↳ add glucose molecules to glycogen.

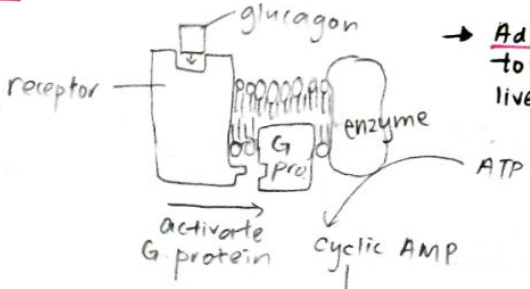
Insulin functions

LOW BLOOD GLUCOSE

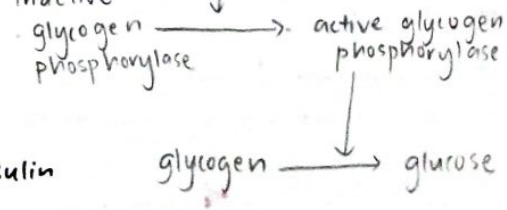
- α cells secrete glucagon, β stop secreting insulin.
- Insulin ↓, rate of uptake of glucose ↓, not 0.
- muscle cells no receptors ∴ no respond to glucagon.
- Glucagon binds to receptor molecules on liver cells, G-protein activated.
- G-protein activates enzyme within membrane that catalyses ATP → cyclic AMP → second messenger
- cyclic AMP binds to kinase enzymes within cyto that activates other enzymes
  - ↳ phosphorylation

Glucagon functions

- Glycogen phosphorylase activated
  - ↳ breakdown glycogen → glucose.
  - ↳ glucose diffuse out through GLUT 2
- Glucose also made from amino acids & lipids → gluconeogenesis



- Adrenaline also binds to diff receptors on liver cell csm
  - ↳ same enzyme cascade.



DIABETES MELLITUS

diabetes

Type 1
- juvenile-onset diabetes
- attack of β cells by immune system / lack genes coding for insulin
- insulin-dependent

Type 2
- non-insulin dependent
- liver & muscle do not respond to insulin

- After meal, glucose conc remains high.
- kidney cannot reabsorb all glucose ∴ remains in urine
- loss of H_2O & salts.
- uptake of glucose into cells is slow (no GLUT)
- cells metabolise fat & proteins ∴ build up of keto-acids
  - ↳ blood pH ↓
- Between meals, glucose conc ↓ ∵ no glycogen stored

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URINE ANALYSIS

- Presence of glucose & ketones → diabetes
  - ↳ blood glucose ↑, ∴ not fully reabsorbed from PCT
- Presence of protein → kidney problem / high bp
  - ↳ most protein too large to be filtered
  - ↳ even if filtered, reabsorbed by endocytosis in PCT, broken down into amino acids & absorbed by blood.

DIP STICKS

- Contain enzymes glucose oxidase & peroxidase
  - ↳ immobilised on small pad at one end of stick.
- glucose $\xrightarrow{\text{glucose oxidase}}$ gluconolactone + H_2O_2
- H_2O_2 + chromogen (colourless) $\xrightarrow{\text{peroxidase}}$ darker compound.
- resulting colour matched against colour chart
- glucose ↑, darkness of colour ↑
- Problem → do not indicate current blood glucose conc.
  - → only while the time urine was collecting in bladder

BIOSENSOR

- Pad impregnated with glucose oxidase.
- Glucose $\xrightarrow{\text{glucose oxidase}}$ gluconolactone
  - ↳ At the same time electric current generated & amplified
- Glucose ↑, current ↑, reading ↑

HOMEOSTASIS IN PLANTS

- Stomata control entry of CO_2 into leaf. → open & close even in constant light
- Open in response to:
  - → light intensity
  - → CO_2 conc ↓ in air spaces in leaf
  - ↳ when open CO_2 ↑ but H_2O ↓ (transpiration)
- Close in response to:
  - → darkness
  - → CO_2 conc ↑ in air spaces
  - → humidity ↓
  - → temp ↑
  - → H_2O ↓
  - ↳ when close, CO_2 ↓ but H_2O ↑

CLOSING OF STOMATA

- H^+ pump stops & K^+ leave guard cell & enter neighbouring cells
- H_2O leaves down Ψ grad. ∴ Guard cells become flaccid.
- stomata close
- only when conserving H_2O important (transpiration

OPENING OF STOMATA

- ATP-powered proton pumps in guard cell csm actively transport H^+ out.
- H^+ conc. inside ↓ ∴ K^+ channels open & K^+ move in.
  - ↳ ∵ cell -vely charged & has low conc. of K^+
  - ↳ diffuse down electrochemical grad.
- Extra K^+ lower Ψ ∴ H_2O enters through aquaporins
- Guard cells become turgid ∴ stomata opens
- Guard cells hv unevenly thickened walls

- → Bundles of cellulose microfibrils arranged as loops ∴ increase in length not diameter

- Ends of guard cells are joined, thin outer walls bend more readily ∴ Guard cells curve & pore opens

ABSCISIC ACID (ABA)

- → stress hormone
- → Guard cells have ABA receptors
- → ABA inhibits H^+ pumps ∴ H^+ not pumped out
- → ABA stimulates movement of Ca^{2+} into cyto through csm & tonoplast
- → Ca^{2+} acts as second messenger → activates channel protein to open ∴ allow -ve charge ions to leave guard cell
- → Stimulates opening of K^+ channel proteins ∴ K^+ out of cell
- → Stimulates closure of channel proteins that allow K^+ to enter
  - ↳ $[K^+]$ in cell ↓ ∴ Ψ ↑
- → H_2O leaves by osmosis, guard cell flaccid, stomata close