

# **DISORDERS OF WATER & ELECTROLYTE METABOLISM**

LECTURE IN PATHOPHYSIOLOGY  
DENTAL MEDICINE  
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**Water**

### AGE DEPENDENCE OF FLUID HOMEOSTASIS

Age	Total water %	Daily exchange %
newborn	79	
3-6 mo.	70	14-16
7-12 mo.	60	12-15
adult man	60	2-4
adult woman	51	2-4

Newborns - ECS > ICS, danger of dehydration  
 In old age - impaired adaptation, danger of dehydration + less muscles, much adipose tissue - less water  
 Women - much adipose tissue, less water than men  
 Obese people - much fat, less water

### DISTRIBUTION OF WATER IN HUMAN BODY

Compartment	Volume litres	% of body mass	% of total water
ICS	28	40	67
ECS	14	20	33
ISF	11	15,7	26
IVF	3	4,3	7
SUMMA	42	60	100

Amount of water in body of young adult man, weight 70 kg

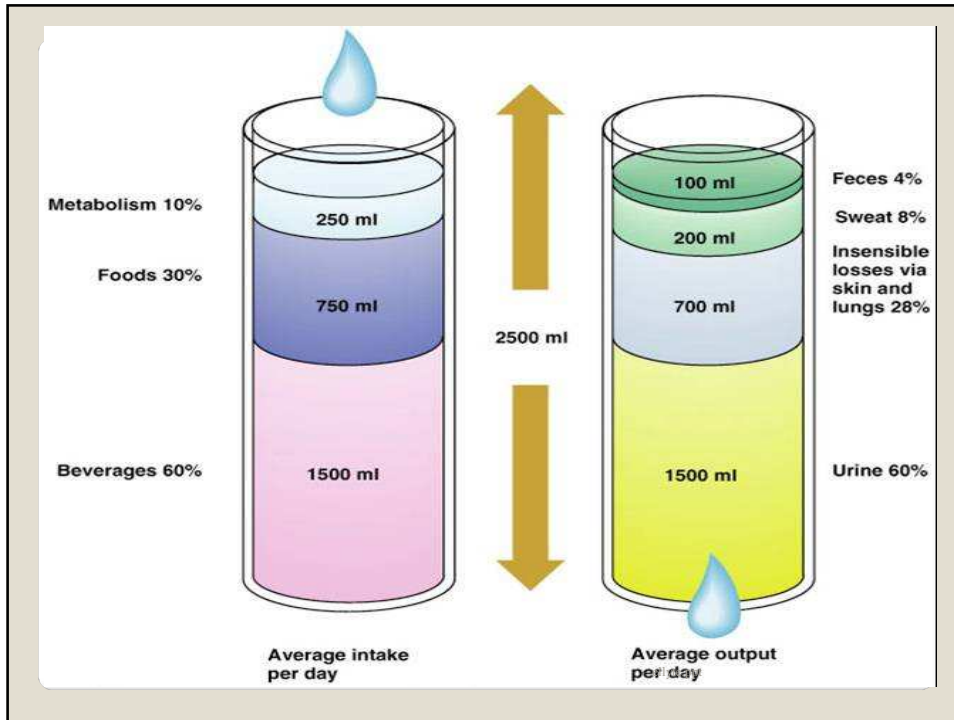
## Water intake

- beverages 1,0 - 1,5 l/d
- water in food cca 1 l/d
- water from metabolism cca 0.3 l/d
 

oxidation of	100 g proteins	35 ml water
	100 g sugar	60 ml water
	100 g fat	107 ml water
- Total intake of water cca 2.0 – 2.5 l/d

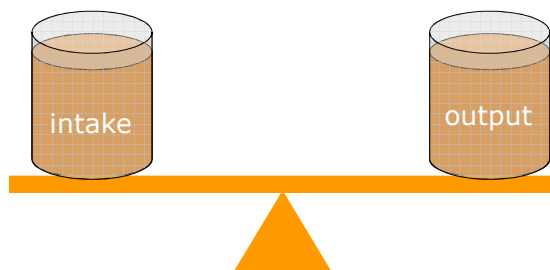
## Water output

- Urine 1.0 – 1.5 l/d
- Perspiratio 0.3 – 0.6 l/d
  - Skin (sweating) 0.2 – 0.4 l/d  
(more – hot environment, physical activity, fever)
  - Lungs – respiration cca 0.2 l/d
- feces 0.1 – 0.2 l/d (more in diarrhea)
- Increased output
  - vomiting
  - bleeding
  - redistribution of water - edema
- Total output of water cca 2.0 – 2.5 l/d

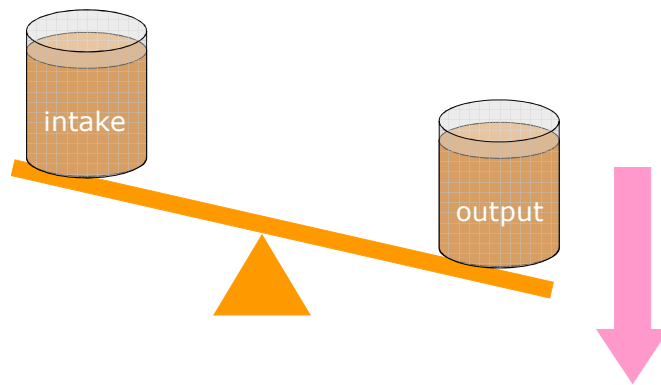


## Water homeostasis

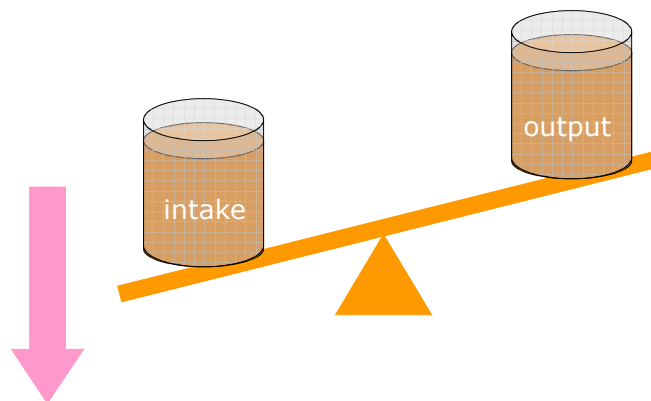
Water balance – equilibrium between intake and output of water



Water deficiency - ↑ thirst

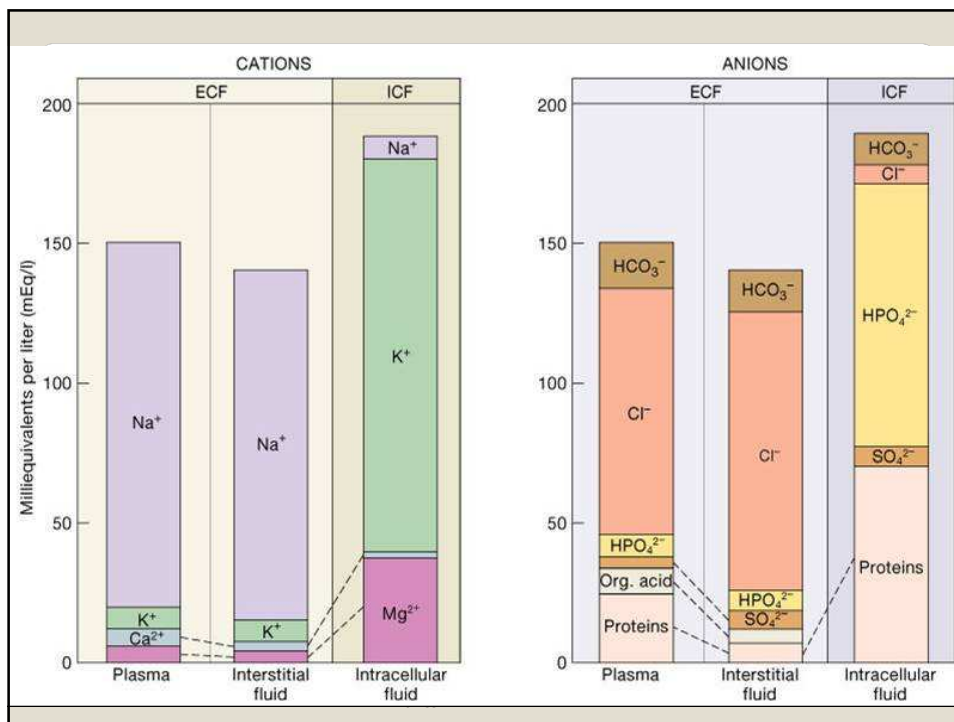


Water excess - ↑ urination



## Electrolytes

Ion	Amount in body	Plasma mmol/l	Cells mmol/l
Sodium, Na <sup>+</sup>	92 g 4 mol	141	10
Potassium, K <sup>+</sup>	100-140 g 2,5-3,5 mol	4	155
Calcium, Ca <sup>2+</sup>	1200 g 30 mol	2,5	< 0,001 (uneven in organells)
Magnesium, Mg <sup>2+</sup>	26,5 g 1,1 mol	1	15
Chloride, Cl <sup>-</sup>	50 g 1,4 mol	103	8
Phosphate (as phosphorus)	775 g 25 mol	1	65



## Osmolality of plasma

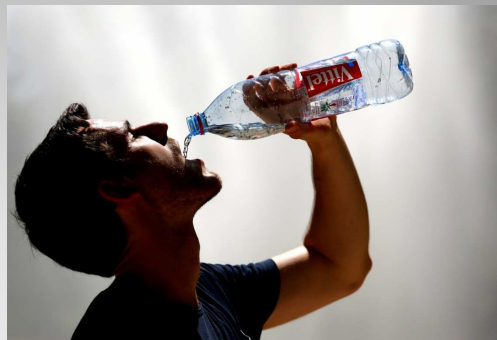
Osmolality - mmol/kg of solvent

Osmolarity - mmol/l of solvent

$$\text{Osmolarity of plasma} = 2 * [\text{Na}] + [\text{glucose}] + [\text{urea}]$$

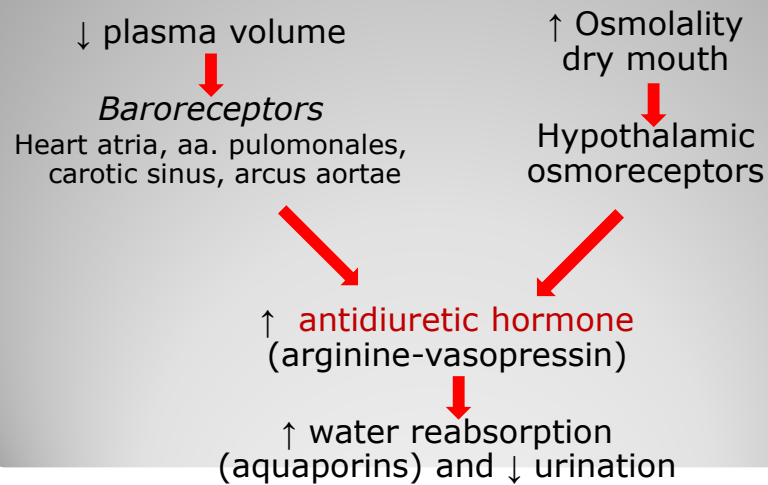
cca  $290 \pm 5$  mmol/l

(kations 140 mmol/l + anions 140 mmol/l + glucose 5 mmol/l + urea 5 mmol/l )



## Regulation of water and sodium homeostasis

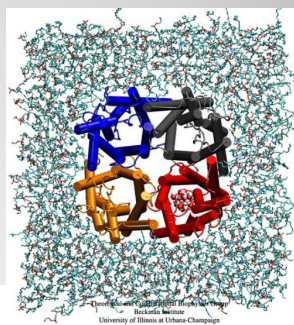
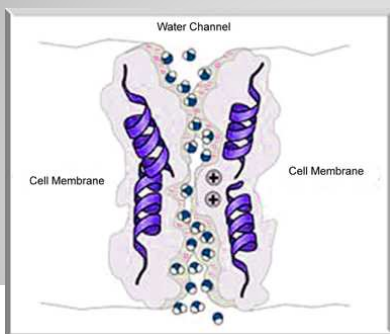
### Antidiuretic hormone





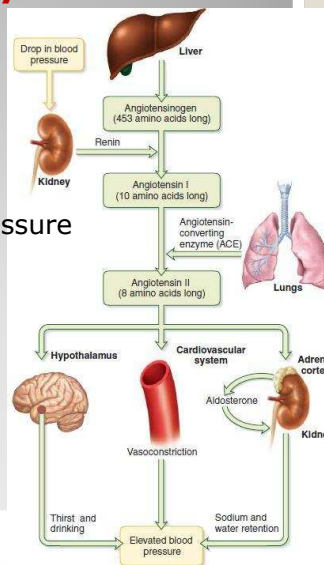
## Aquaporins

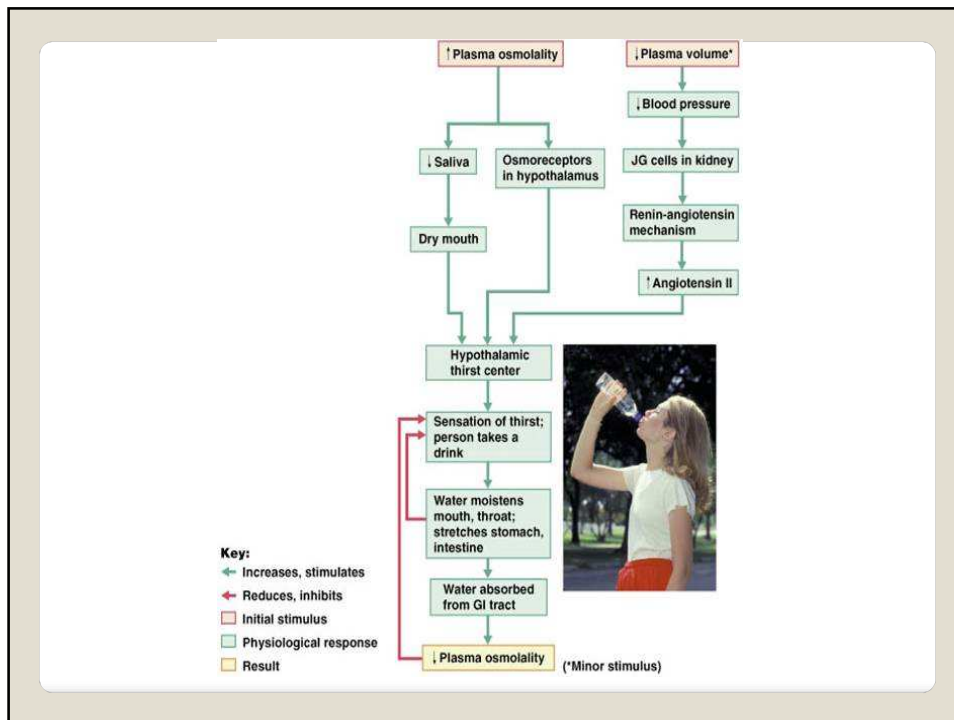
- Water channels
- Conduct water through cell membrane
- **2003 – Nobel price for chemistry**



## Renin-angiotensin-aldosterone system

- Angiotensin II
  - Vasoconstriction – ↑ blood pressure
  - Antiinflammatory effect
- Aldosterone
  - Reabsorption of sodium
  - Secretion of potassium





## Natriuretic peptides

- peptides which induce natriuresis

Types:

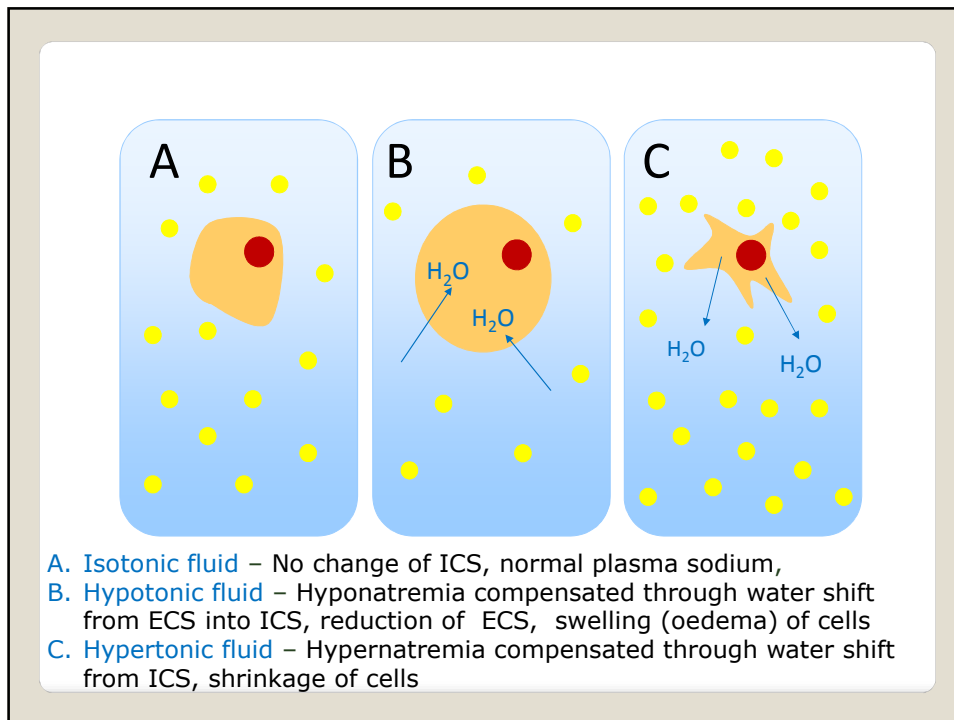
- **Atrial natriuretic peptide (ANP)** – produced in atria
- **Brain natriuretic peptide (BNP)** - ventricles in humans, brains in pigs
- **C-type natriuretic peptide (CNP)**
- **Dendroaspis natriuretic peptide**
- **Urodilatin** - kidneys



## **Disorders of water and sodium homeostasis**

### **DISTURBANCES OF THE SYSTEM**

- No pure forms – loss of water, salt...
- Immediate reaction of compensatory systems
- ECS is in contact both with external environment and with ICS
- ICS is in contact only with ECS
- Plasmatic concentrations are not amounts and does not inform on dynamics of compounds



## POSSIBLE CAUSES AND MECHANISMS

- Extreme deviations of external environment
  - *Dehydration from insufficient water intake*
- Disturbances caused by damaged function of effector systems (kidneys, GIT, etc.)
  - *Diarrhoea, vomitus, kidney diseases*
- Disturbances caused by erroneous regulation (CNS, ADH, aldosterone)
  - *Diabetes insipidus, Conn sy., SIADH*
  - *Heart failure & RAA activation*

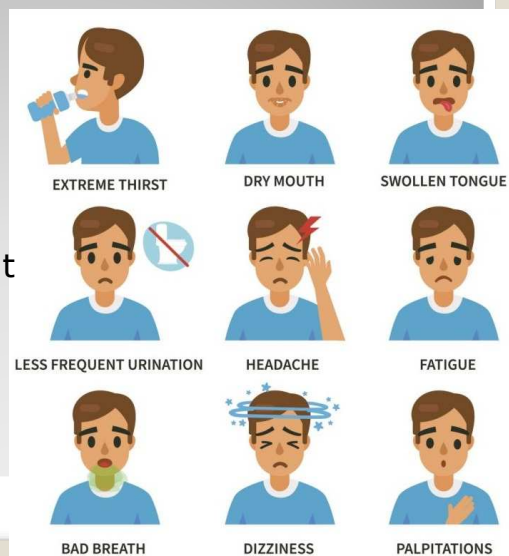
## WATER DEFICIENCY

### Causes

- Insufficient fluid intake
- Inability to drink (*loss of consciousness*)
- Losses through GIT (*diarrhoe, vomitus*)
- Losses through kidneys
  - (*diuretics, osmotic diuresis, kidney diseases, m. Addison*)
- Losses through skin (*increased sweating, burns*)
- Displacement into third place (*ileus, ascites*)
- Blood loss (?)

## WATER DEFICIENCY Signs

- hypotension,
- tachycardia,
- dry skin,
- thirst,
- oliguria & decreased sodium excretion,
- increase of hematocrit



## Water deficiency signs in oral cavity

- Xerostomia
  - Decreased amount of saliva
  - Dry skin and mucous
  - Salivary gland swelled and painfull
  - Inflammatory changes – cheilosis, glossitis
  - ↑ risk of caries
  - ↑ risk of infection - candidiasis
- Dysphagia – problem with swallowing
- Dysfonia – loss of voice
- Dysgeusia – loss of taste



## WATER RETENTION

### Causes

—Increased fluid intake—

- Increased intake & disturbed regulation – SIADH
- kidney failure
- nephrotic sy.
- heart failure
- liver cirrhosis

Symptoms: Oedema.

## Hyponatremia Na <135 mmol/l

### Causes

- Loss of sodium
  - Addison disease
  - Diuretics
  - GIT diseases – vomiting, diarrhea
- Decreased intake of sodium (rare)
  - Combination of low sodium diet and treatment by diuretics
- Dilute hyponatremia
  - Drinking too much water – water intoxication
  - SIADH – antidiuretic hormone hyperproduction
  - Kidney failure
  - Heart failure
  - Liver cirrhosis
  - Shift of water from ICF to ECF (hyperglycemia, hyperlipidemia, hyperproteinemia)

## Hyponatremia



Excessive Vomiting



Diuretics



Drinking too much water



Excessive Diarrhea



Heart, kidney and liver problems



Dehydration



Inadequate Salt Intake



Fluid shift from ICF to ECF

## Hyponatremia

### Clinical signs

- nausea and vomiting,
- headache,
- confusion,
- fatigue,
- irritability,
- muscle weakness,
- spasms, cramps, seizures,
- edema
- hypotension
- unconsciousness, coma

### HYPONATREMIA SIGNS AND SYMPTOMS

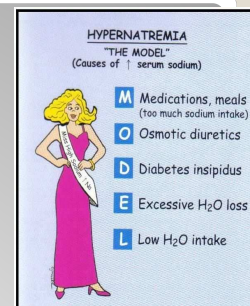
NURSE.PUFF

- S**tupor/coma
- A**norexia, (nausea and vomiting)
- L**ethargy
- T**endon Reflexes (decreased)
- L**imp muscles (weakness)
- O**rthostatic hypotension
- S**eizures/headache
- S**tomach cramping

## Hypernatraemia >145 mmol/l

### Causes

- Increased sodium intake
  - per os
  - parenteral
- Decreased elimination of sodium
  - Renal insufficiency
  - Endocrine diseases – hyperaldosteronism (Conn syndrome), Cushing syndrome
- Loss of water
  - Diabetes insipidus
  - Decreased water intake - unconsciousness , brain injury or tumor
  - Loss of water from GIT (diarrhea)
  - Sweating – fever





## Hypernatraemia

### Clinical signs

- Thirst
- Confusion
- Hyperreflexia, muscle spasms
- Hypotension
- Tachycardia
- Coma



## Disorders of chloride homeostasis



## Hypochloremia < 97 mmol/l

### Causes

- Hyponatremia
- Metabolic alkalosis
- Cystic fibrosis

### Clinical signs

- No clinical signs
- Signs of hyponatremia
- Metabolic alkalosis



## Hyperchloremia >109 mmol/l

### Causes

- Dehydration
- Diabetes insipidus
- Diuretics
- Hyponatremia
- Metabolic acidosis

### Clinical signs

- No clinical signs
- Dehydration
- Metabolic acidosis



## Disorders of potassium homeostasis

### POTASSIUM HOMEOSTASIS

- Serum concentration: 3,8 – 5,5 mmol/l\*
- Total amount depends on muscle mass (young > old; man > women)  
37 – 52 mmol/kg body mass
- Intake: 2-6 g/d = 50-150 mmol/d
- Excretion through kidneys 10 – 20 mmol/d (0,4 – 0,8 g/d).
- Inverse association with Na excretion
- GIT excretion is important in kidney failure and in pathological conditions (diarrhoea)

\*Depends on method. Preanalytic errors - hemolysis!

## **FUNCTIONS OF POTASSIUM & INTERPRETATION OF RESULTS**

### ***Functions***

- intracellular osmotic pressure
- resting & action potential
- enzyme activity, proteosynthesis

### ***Problems:***

- assessment of cell homeostasis from extracellular concentration
- pH changes: exchange H/K between ECF/ICF

## **INTERNAL & EXTERNAL BALANCE**

### ***internal – ECF/ICF***

- acidosis: H<sup>+</sup> enters the cells, K<sup>+</sup> out into ECF
- alkalosis: H<sup>+</sup> into ECF, K<sup>+</sup> enters the cells
- K<sup>+</sup> entry into cells: insulin (together with glucose), aldosterone, adrenaline
- rapid cellular proliferation (treatment of pernicious anaemia with B<sub>12</sub> vitamin)
- cell necrosis, hemolysis (crush sy, malignancies), K<sup>+</sup> into ECF

### ***external – ECF/environment***

- kidney or GIT retention/losses, parenteral intake
- dietary deficiency/excess as an additional factor

## HYPOKALAEMIA < 3.5 mmol/l

### Causes

#### *Disorders of external balance*

- GIT – diarrhoea, vomitus, tumors of colon, rectum, pancreas
- Kidneys - diuretics, polyuric stage of renal failure, hereditary tubulopathies,
- Primary & secondary hyperaldosteronism, abuse of liquorice, Cushing, ectopic ACTH production

#### *Disorders of internal balance*

- Treatment of diabetic hyperglycaemia with insulin (K<sup>+</sup> entry into cells together with glucose)
- Alkalosis
- Rapid cellular proliferation
- Familial hypokalaemic periodic paralysis (hereditary)

## HYPOKALAEMIA

### Symptoms

- Membrane hyperpolarisation
- Weakness, constipation, ileus, hypotonia
- Depression, confusion
- Arrhythmia, potentiation of digitalis toxicity
- ADH resistance, polyuria, polydipsia
- ECG flat/inversed T, prolonged PR, ST depression, prominent U

## HYPERKALAEMIA >5.5 mmol/l

### Causes

#### *Disorders of external balance*

- Decreased excretion
- Increased intake (infusions, NaCl substitution) only in the case of impaired kidney function
- m. Addison, adrenogenital sy., inhibitors of angiotensin converting enzyme

#### *Disorders of internal balance*

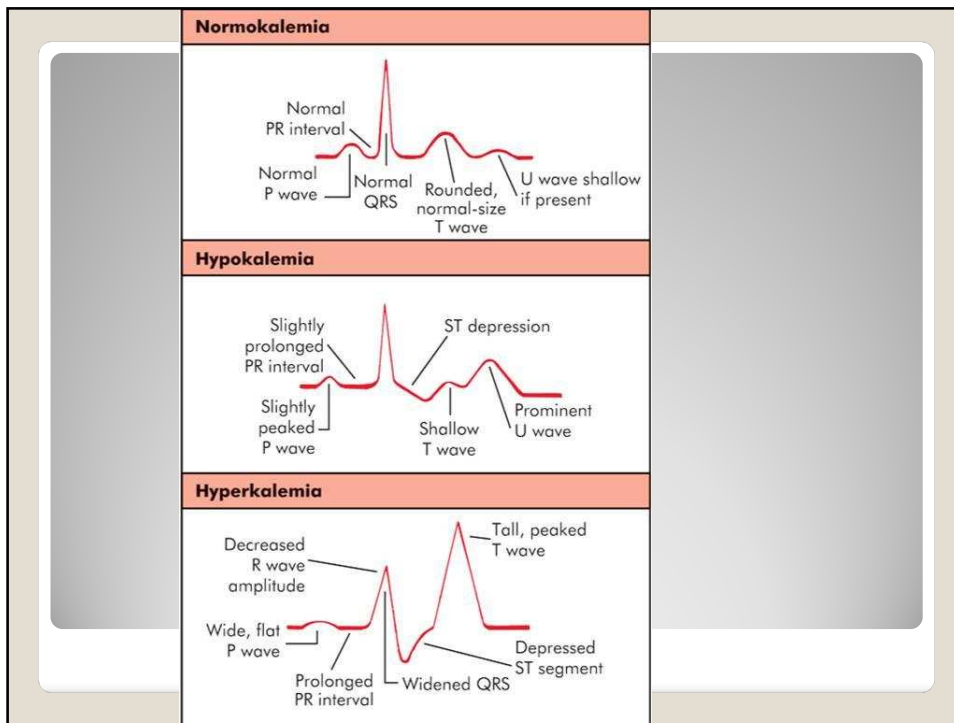
- Acidosis
- Cell necrosis - rhabdomyolysis, burns, cytostatic treatment of malignancies
- Digitalis overdosis
- Hyperkalaemic periodic paralysis (hereditary)
- Malignant hypertermia (hereditary)

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## HYPERKALAEMIA

### Symptoms

- Low resting potential, short cardiac action potential, increased speed of repolarization →
- Can kill without warning
- Ventricular fibrillation and cardiac arrest may be the first signs! (if you do not check K & ECG)
- ECG: abnormal/absent P; broad QRS, peaked T, ST depression



The image shows three human skeletons from a side view, illustrating the effects of different calcium levels on bone density. The skeleton on the left appears to have normal bone density. The middle skeleton shows signs of osteoporosis, with noticeably thinner and more fragile bones. The skeleton on the right shows signs of osteomalacia, with bones that are thickened and deformed, particularly in the lower extremities.

**Disorders of calcium homeostasis**

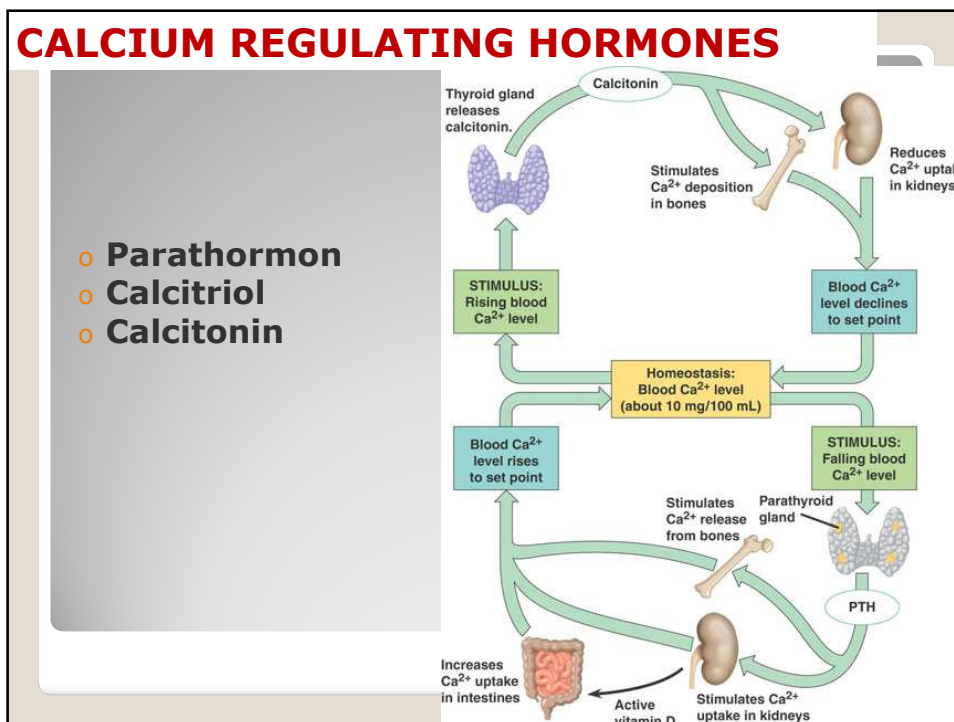
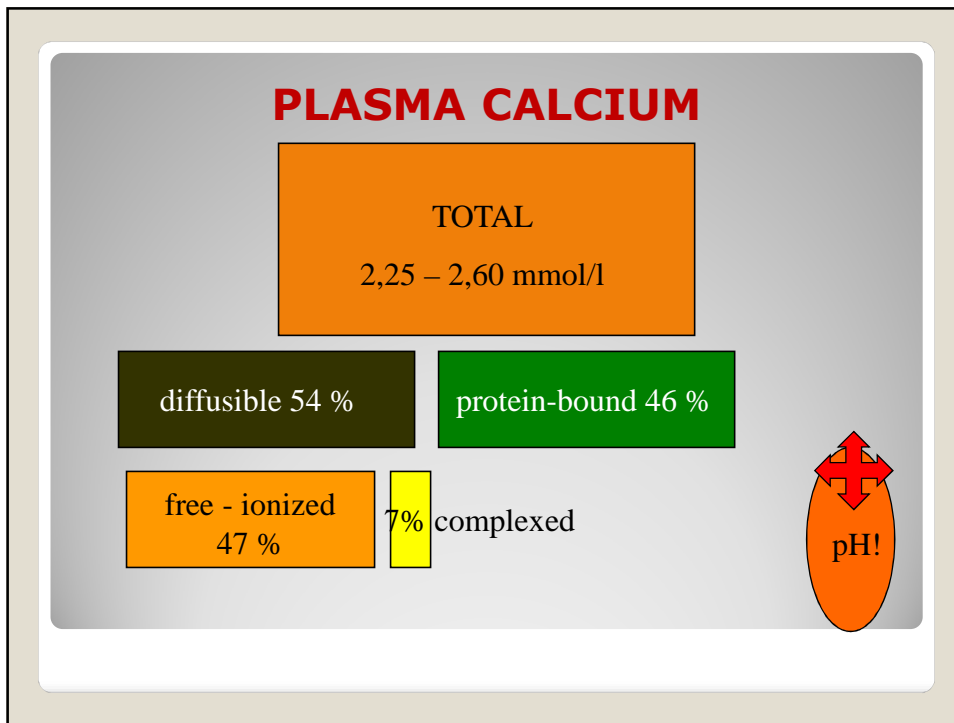
## CALCIUM

• Total body	1200 g	30 mol
• ECF	0,9 g	22,5 mmol
• Plasma	0,36 g	9,0 mmol
• Bone / ECF exchange		500 mmol/d
• Daily losses		25 mmol/d (1g)
◦ urine	6 mmol	
◦ faeces	19 mmol	
◦ skin	0,3 mmol	

## FUNCTIONS OF CALCIUM

- |                  |  |
|------------------|--|
| • Structural     | • Bone, teeth  |
| • Neuromuscular  | • Control of excitability;<br>Neurotransmitter release |
| • Blood          | • Muscle contraction                                   |
| • Signal systems | • Coagulation  |
|                  | • Messenger  |





## FUNCTIONS OF PARATHORMON

### BONE

- Release of calcium ↑ [Ca<sup>2+</sup>]
- Osteoclastic resorption

### KIDNEY

- Calcium reabsorption ↑ [Ca<sup>2+</sup>]
- 2<sup>nd</sup> hydroxylation of vit.D ↑ Ca, P
- Phosphaturia ↓ [PO<sub>4</sub>]
- Decrease of HCO<sub>3</sub><sup>-</sup> reabsorption ↓ pH

## HYPOCALCAEMIA < 2.2 mmol/l

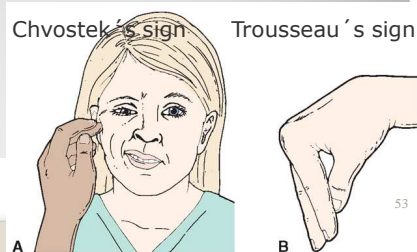
### Causes

- Hypoparathyroidism
  - Congenital (with Di George sy.)
  - Acquired – autoimmune, surgery, hemochromatosis, tumors
- Pseudohypoparathyroidism
- Magnesium deficiency (pseudo ?)
- Deficiency of vitamin D
- Disorders of vitamin D metabolism – end stage renal disease
- Acute pancreatitis, transfusions with citrate, neonatal

## HYPOCALCAEMIA

### Symptoms

- Stupor, numbness, paraesthesia
- Muscle cramps and spasms „tetany“
- Laryngeal stridor
- Convulsions
- Chvostek+, Trousseau+, long QT on ECG
- ❖ Cataract in chronic hypocalcaemia
- ❖ Rickets (rachitis) in vitamin D deficiency



## HYPERCALCAEMIA > 2.7 mmol/l

### Causes

- COMMON (90% of all)
  - Primary hyperparathyroidism
  - Malignancies – bone metastasis
- LESS COMMON
  - Thyreotoxicosis, sarcoidosis
- UNCOMMON
  - Lithium treatment, tbc, immobilisation, adrenal failure, renal failure, hereditary

## HYPERCALCAEMIA

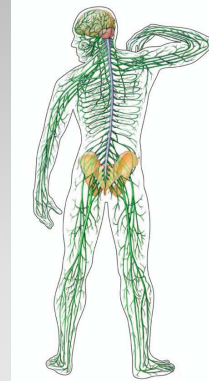
### Clinical signs

- Weakness, tiredness, weight loss
- Impaired concentration, drowsiness (coma)
- Anorexia, nausea, vomiting, constipation
- Polyuria, dehydration
- Renal calculi, nephrocalcinosis
- short QT, arrhythmias

## Hyper- and hypocalcemia in oral cavity

- Hypercalcemia
  - Jaw bone demineralization
  - Loss of lamina dura
  - Osteitis fibrosa cystica – increased osteoclastic resorption, hemorrhage and cysts formation
- Hypocalcemia
  - Hypoplasia and discoloration of teeth
  - Possible tetany cramps





## Disorders of magnesium and phosphates homeostasis

### MAGNESIUM

- 60 % in bones, higher in ICF than in ECF
- Only 0,3 % in blood, 30% protein bound
- Serum 0,7 – 1,0 mmol/l
- Regulator is not known! *adrenal medulla, insulin, parathormon ???*
- Regulated resorption from GIT ?
- Excretion through urine and stool

## MAGNESIUM

- Neuromuscular excitability (inhibition – mediated through decreased secretion of acetylcholine?)
- Bone structure
- Enzyme activity, energy production, transport mechanisms, ribosomes
- Regulation of haemocoagulation and membrane function
- Cardioprotective antiischemic, antihypoxic effects
- Sedative effect on NS
- Antihypertensive
- Antithrombotic

## Hypomagnesiemia < 0.7 mmol/l

### Causes

- Deficiency associated with soil and plant deficit ⇒ grass tetany of cattle
- Some drugs and stress can increase excretion
- Unhealthy diet (alcohol)
- High doses of calcium

### Signs

- Spasms
- Tiredness, irritability, tremor
- Dysmenorea, preeklampsia
- Arrhythmias

## Hypermagnesiemia > 1 mmol/l

- Rare

## PHOSPHATE

- 85 % in bones
- in ICF and in ECF
- In plasma – phospholipids, phosphate esters and ionized phosphate
- Regulation – PTH, vit. D and calcitonin (together but opposite with calcium)

## Hypophosphatemia < 0.8 mmol/l

### Causes

- Intestinal malabsorption
  - Vit. D deficiency
  - Use of Mg- and Al-containing acids that bind phosphates
  - Alcohol abuse
  - Malabsorption abuse
- Increased renal secretion
  - Hyperparathyroidism

### Signs and symptoms

- Only in higher deficit
- Disturbed energy metabolism – nerves and muscles dysfunction
- Erythrocyte, leukocyte and platelets dysfunction
- ↑ risk of infection
- Hemorrhage

## Hyperphosphatemia > 1.6 mmol/l

### Causes

- Destruction of cells – tumors or anticancer therapy
- Long term using of phosphate-containing drugs (laxatives)
- Hypoparathyroidism

### Signs and symptoms

- Symptoms of hypocalcemia – tetany
- Calcification of tissues

## Edema

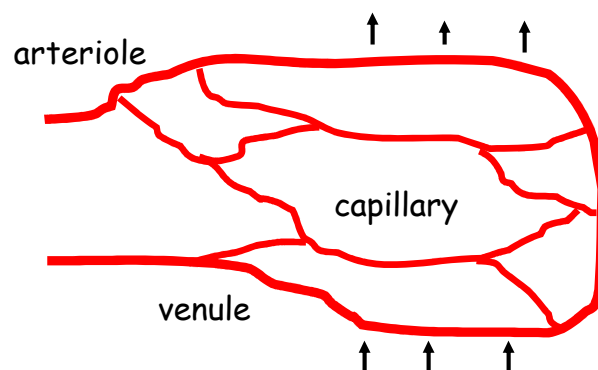


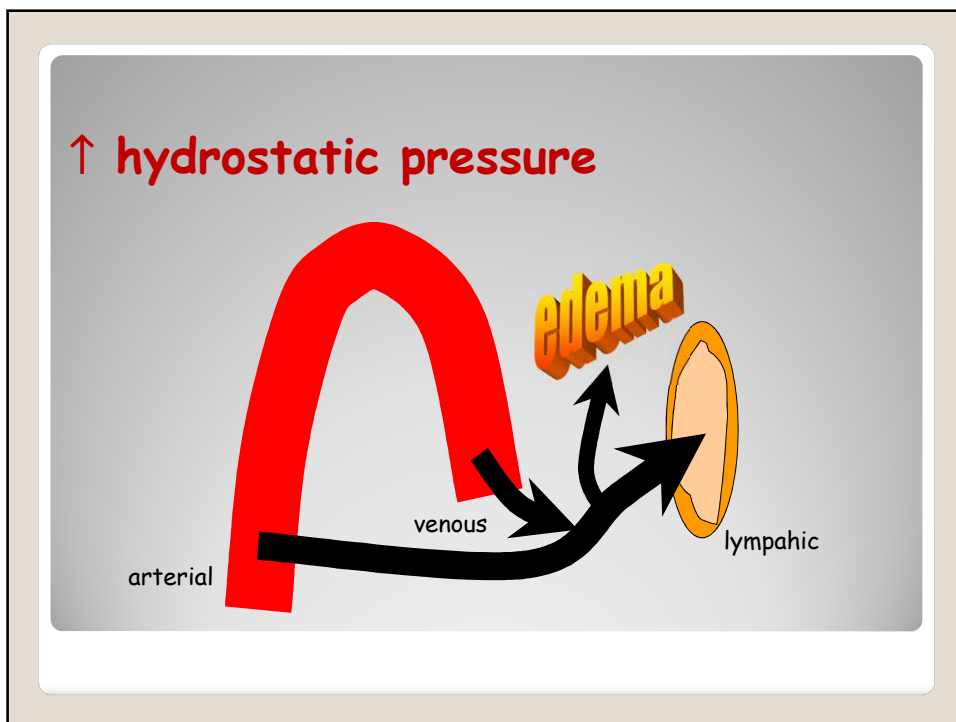
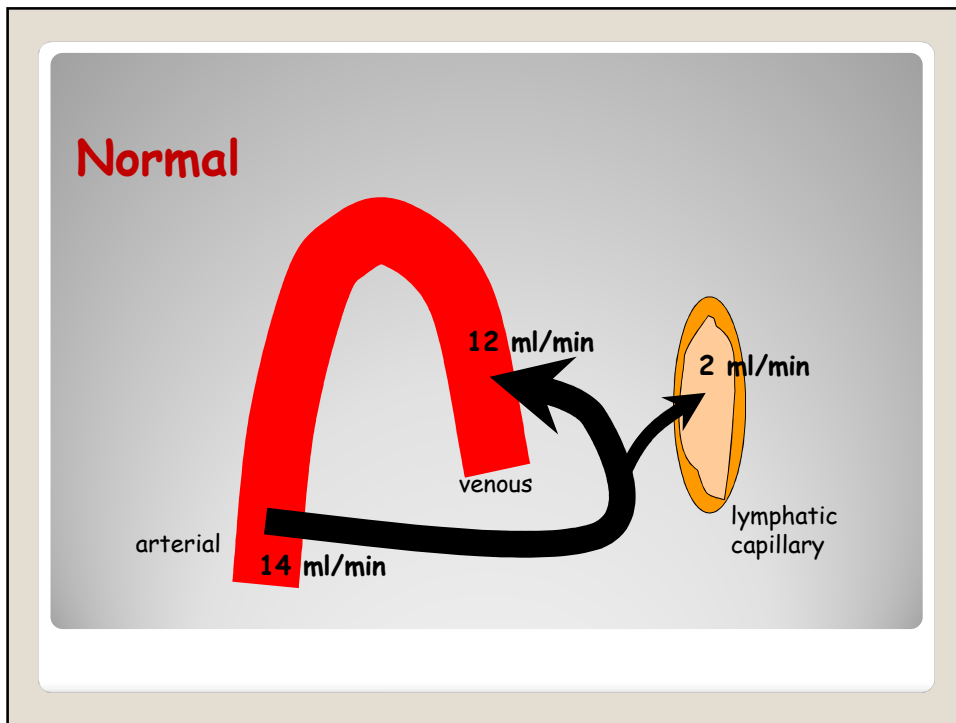


## Starling's hypothesis

1. Hydrostatic pressure in capillaries    avg. 20 – 25 mmHg  
     arterial 30 – 35 mmHg  
     venous 15 – 20 mmHg
2. IST hydrostatic pressure  
    → transmural pressure
3. Plasma colloid osmotic (oncotic) pressure    28 mmHg
4. IST colloid osmotic pressure                 4.5 mmHg  
    → oncotic transmural pressure
5. Fluid draining from IST via the lymphatic vessels

## Starling forces





## ↑ hydrostatic pressure

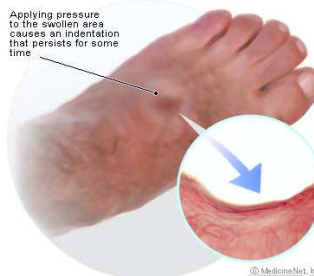
### Causes

- venous obstruction
- heart failure
  - left – pulmonary oedema
  - right – peripheral oedema
- postural oedema



### Pitting Edema

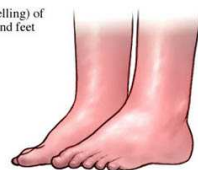
Applying pressure to the swollen area causes an indentation that persists for some time

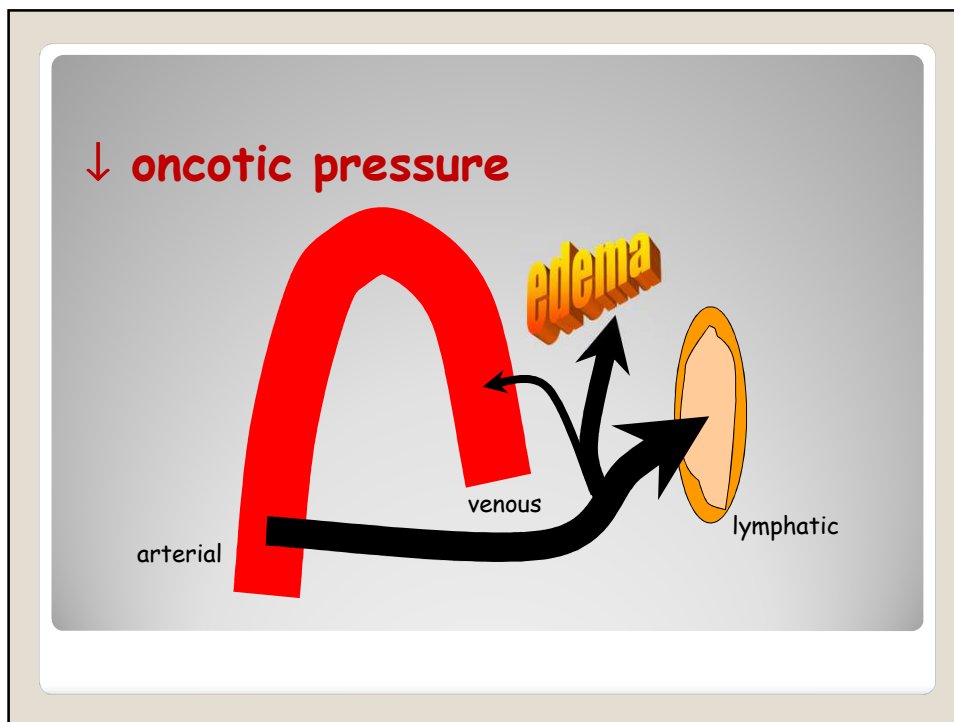


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Edema (swelling) of the ankles and feet

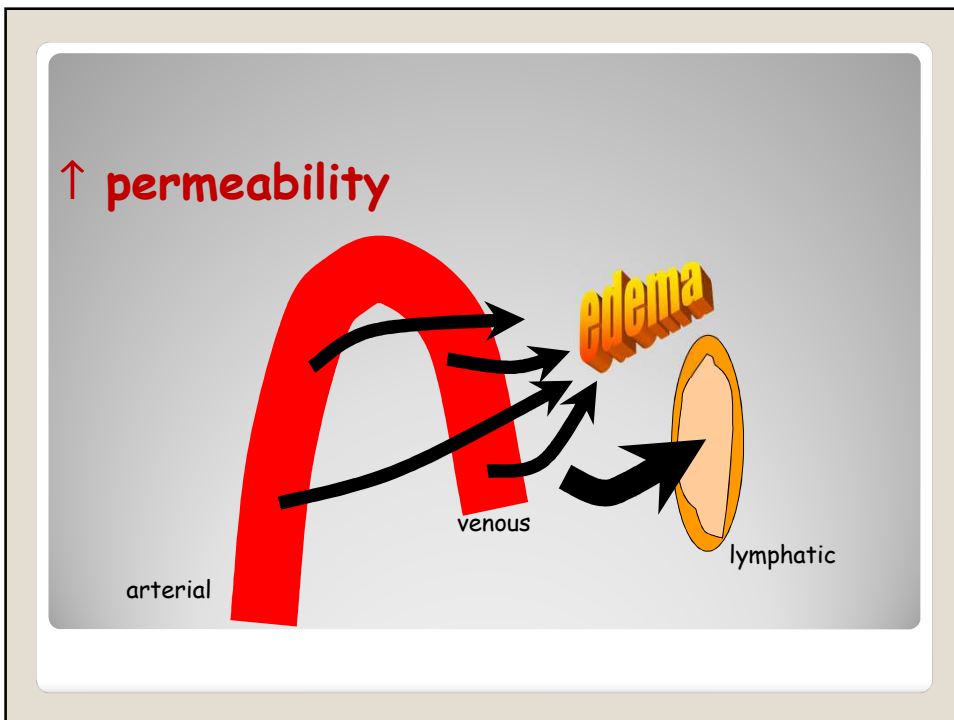
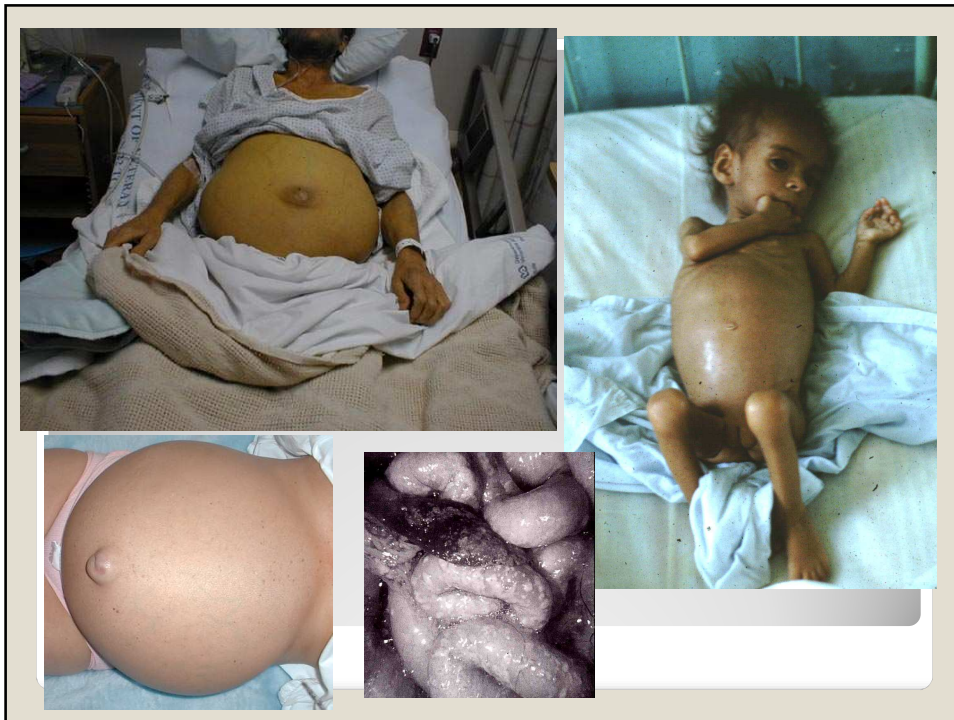




## **↓ oncotic pressure**

### Causes

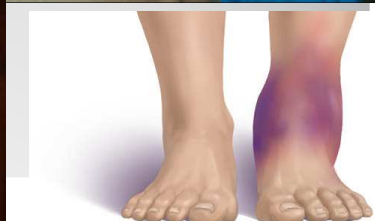
- hypoproteinaemia
  - liver diseases
    - cirrhosis
      - ↓ oncotic pressure + ↑ hydrostatic pressure (portal hypertension)
  - nephrotic syndrome
  - protein malnutrition – kwashiorkor
  - some metabolic diseases

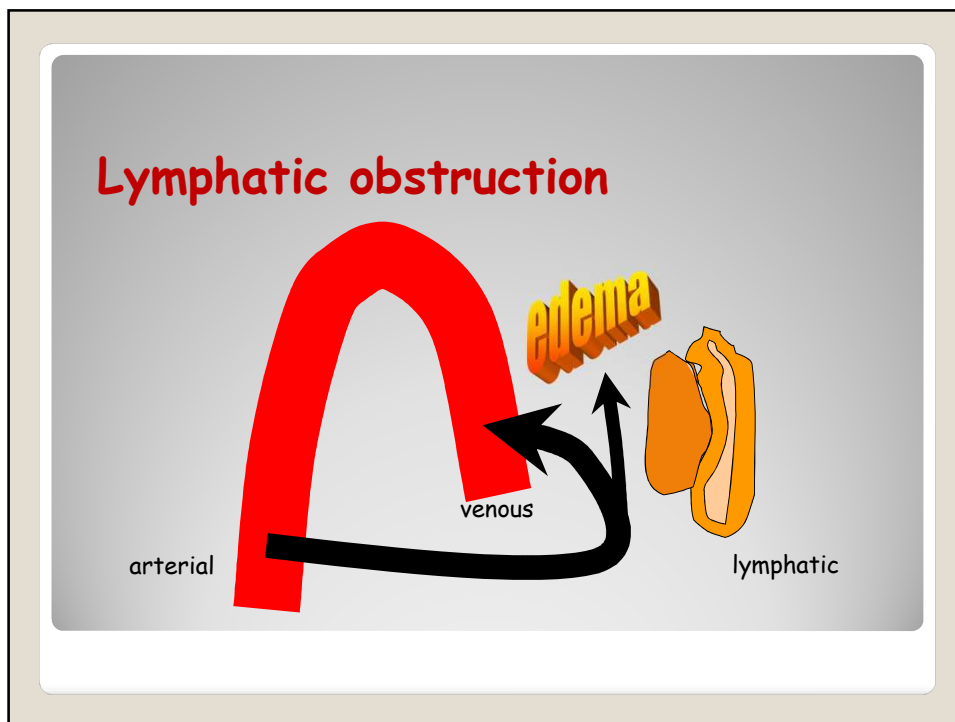


## ↑ permeability

### Causes

- inflammation – mediators
- allergy - histamine
- hypoxia - ↓pH (mountain disease)
- toxic





## Lymphatic obstruction

lymphoedema (woody oedema)

### Causes

- lymfatic obstruction
  - parasites (filariasis)
  - cancer of lymph nodes
  - surgery or radiation therapy (breast cancer)
  - inflammatory changes - lymphangitis

