Physiology of the digestive system

Objectives
Basic functions of the digestive system
  (motility, secretion, composition of digestive juices, digestion of nutrients, absorption, control of GIT function)

Tasks
• Observation of the effect of ptyalin in saliva
• Transport of food through oesophagus
• Determination of glycaemia by glucometer
• Physiological properties of the smooth muscle in antrum pylori (PC programme)
The digestive system

- consists of the **gastrointestinal tract** (GIT)
- organs of the GIT:
  - oral cavity
  - oesophagus
  - stomach
  - small intestine
  - large intestine
  - anus

- includes the **associated glandular organs** that empty their contents into the tract
  - salivary glands
  - liver
  - pancreas
Structure of the wall of digestive organs (intestine)

Mucosa (inner layer)
- secretion of the digestive juice
- absorption

Submucosa

Smooth muscle (movements of the GIT)
- circular (internal)
- longitudinal (external)

Serosa – covers GIT organs from outside

Nervous plexes:
- submucosal plexus (Meissner´s) in submucosa
- myenteric plexus (Auerbach´s) between circular and longitudinal muscles
General functions of the digestive system

- most of the food consumed - in form of solids and macromolecules that are not readily absorbable
- in GIT food is processed into products that can be absorbed and utilized in the body

1. Digestion
- mechanical and chemical breakdown of substances contained in food (usually macromolecules) into small molecules that can be absorbed

2. Secretion
- production and release of digestive juices for chemical breakdown of the food

3. Motility
- movements of the GIT organs
4. Absorption (assimilation)  
- transfer of the digestion products from the lumen across the intestinal wall into blood or lymphatic vessels (fat)

5. Storage and elimination of faecal waste  
- indigestible and undigested material from food

6. Protection (mechanical, chemical, immunological)  
- protection against foreign harmful substances, involves e.g.
  - lymphatic tissue in the wall of GI organs - part of the immune system
  - gastric juice – strong acid, kills bacteria
  - mucus – protection of the mucosa (mechanical, chemical)
  - gut bacteria – protect against harmful bacteria, etc.
  - saliva - contains bacteriostatic substances (lactoferrin, lysozyme)

- protected are not only organs of the digestive system, but also the whole body

7. Endocrine function  
- secretion of hormones with local effect (gastrin, secretin...) or general effect (insulin, glucagon...)
Motility in the digestive system

- performed by the contraction/relaxation of smooth muscles in the wall of GI organs
  - circular (a)
  - longitudinal (b)

Mixing movements

- serve for the **crushing the ingested food**
- decrease the particle size-increase the surface area for action of digestive enzymes
- **mix** the GI secretions with food components
- bring products of digestion into contact with the absorptive surfaces of the mucosa
Mixing movements in the small intestine

a/ Segmentation movements (a)
- contractions of the circular muscle at intervals of about 1 cm along the intestine (divide the gut into segments)
- as one set of segmentations relaxes a new set of contractions begins in points between the previous one

b/ Pendular movements
- contractions of the longitudinal muscle - support mixing of the chyme
Propulsive movement - peristalsis
- moves the content of the GI system forward
  (in oesophagus, stomach, gut, pancreatic and bile ducts)

- the basic propulsive movement is **peristalsis**

**Peristalsis** - is a reflex activity
  (automatic, involuntary response to stimulation) of the smooth muscle in GIT
when meal (bolus) enters the GIT (e.g. oesophagus, intestine)
- it stimulates mechanoreceptors in wall of GI organs
- as a response the smooth muscles react:

1. behind the bolus:
   contraction of the circular muscle + relaxation of the longitudinal muscle
   (pushes food forward and prevents movement in backward direction)

2. in front of the bolus:
   relaxation of the circular muscle + contraction of the longitudinal muscle

- receiving segment is formed
- this allows the bolus to propel
- peristalsis proceeds as a wave in frontal direction

- in interdigestive periods - basic peristaltic activity – slow
Secretion in the alimentary tract
General composition of the digestive juices

• **water** – solvent that provides optimum environment for action of enzymes

• **inorganic substances** (electrolytes): $\text{HCO}_3^-$, $\text{K}^+$, $\text{Na}^+$, $\text{Cl}^-$, $\text{Ca}^{2+}$, $\text{Mg}^{2+}$, phosphates
  – generate optimum pH and osmotic gradient

• **digestive enzymes** - catalyze the break down of nutrients

• **mucus** - glycoprotein produced in most parts of the GIT in mucous (goblet) cells
  - coats the wall of the organs of GIT - protects mucosa from excoriation+ digestion
  - acts as a lubricant, food slides easier along epithelium
  - adheres to the food particles - helps to form bolus
  - helps to form faecal mass

• **other substances** - with specialized function e.g.
  - antibacterial lysozyme in saliva,
  - intrinsic factor in gastric juice, etc.
Saliva

• digestive juice, produced in 3 pairs of salivary glands
  - **parotid glands** (serous secretion – rich in \( \alpha \)-amylase)
  - **submandibular gland, sublingual gland, glands of oral mucosa**
    (mucous secretion – rich in mucus)

**Composition**

1. water (99,8%)
2. inorganic substances – electrolytes \( \text{HCO}_3^-, K^+, Na^+, Cl^- \), phosphates
3. digestive enzymes
   • \( \alpha \) - amylase (ptyalin)
     - digestion of starch into maltose and dextrins
     - optimum activity in: pH 5.6 – 6.9, temperature 37°C
     - action of ptyalin continues in the stomach before the food becomes completely mixed with acidic gastric secretions that block action of the enzyme
4. other organic substances
   • lysozyme, lactoferrin, immunoglobulin A – antibacterial action
5. mucus - lubrication, protection
Functions of saliva

- lubrication - wetting of the food – bolus formation
- digestion of the starch
- antibacterial effect (lysozyme, lactoferrin, immunoglobulin A)
- taste sensation – dissolves chemical „tasty“ substances
- buffer system – maintenance of optimal pH in oral cavity
  - optimal for activity of $\alpha$ - amylase
  - prevention of dental plaques (that are built in acidic pH)
- cleans food debris - prevention of dental caries

The volume of saliva

- basal production: 0,5 ml/ min
- increases 6 – 20 times after stimulation (food intake)
- normal volume of saliva 800 – 1500 ml /day
Secretion of saliva

- **salivation = reflex response to stimulation**
  (automatic, involuntary response)

  – stimuli:

1. **direct tactile stimulation** of mechanoreceptors by food (unconditioned reflex)

2. **visual, olfactory stimuli, thinking of food**
   (conditioned reflex)
Task:
Observation of the effect of ptyalin in saliva

Aim of the task
a/ to test the effect of salivary ptyalin on a starch solution
b/ to demonstrate that acidic environment stops the activity of the salivary ptyalin
**Procedure**

- take 30 ml of distilled water into the mouth and retain for 3-5 minutes
- expel the water into a glass (saliva is secreted into water, thus it becomes a solution of saliva)
- take 3 test tubes, label them (1, 2, 3) and put the following liquids into the tubes

- mix and put the tubes into a water bath heated to 37°C
- incubate for 45 minutes (shake the tubes every 5-10 minutes)
• after incubation is finished put 3 drops of the Lugol's solution into each tube

Lugol's solution
• indicator to test the presence of starch
• interacts with the starch giving rise to a dark blue-black colour
• if starch is absent, the solution remains orange to brownish

3 ml of starch solution 3 ml of starch solution + 2 ml saliva solution

3 ml of starch solution + 2 ml saliva solution + 1 ml HCl

- observe and explain the colour of solution in the test tubes

End of the task
Swallowing

- complicated mechanism for passage of food from mouth to oesophagus
- crossing of GIT with respiratory passageways (breathing!)

1. **voluntary phase** - food is voluntarily squeezed by tongue posteriorly to pharynx

   ![Swallowing Diagram](http://upload.wikimedia.org/wikipedia/commons/9/97/Swallow_food.png)

2. **pharyngeal phase** - automatic

   - food stimulates receptors around the opening of pharynx
   - as a response to stimulation
     - the epiglottis covers the opening of larynx - to prevent passage of the food into trachea
     - the soft palate is elevated to close the nasopharynx (to prevent reflux of food)
     - the respiratory centre is inhibited
     - the upper oesophageal sphincter is opened
     - a peristaltic wave originating in the pharynx forces the bolus of food into upper oesophagus
Oesophagus and peristalsis

Oesophagus
- a tube with the primary function to conduct the food to the stomach
- food is transported by **peristalsis**
- primary peristalsis - a continuation of peristaltic wave that begins in the pharynx
- if the primary peristaltic wave fails to move all the food into the stomach, **secondary** peristaltic waves result from the distention of the oesophagus by the retained food

- lower oesophageal (cardiac) sphincter - the circular muscle at the lower end of oesophagus
  - normally remains constricted
- when a peristaltic wave passes toward the stomach, the sphincter relaxes and allows propulsion of the swallowed food into stomach

http://t3.gstatic.com/images?q=tbn:ANd9GcROR85aAFFEE7XCXHVVV9aXjp0bL_imB_D8SEOb1ORI7ONDtTak
Task: Transport of food through oesophagus
Measure the time of transport through oesophagus
a/ for a solid food (biscuit, cake, bread, etc.)
b/ for a liquid (water)

Procedure
- the examinee (patient) sits on a chair
- the examiner (doctor) lays the stethoscope under the sternum
- the examinee swallows a piece of roll – in this moment the stopwatch is switched on
- when the bolus gets into stomach a weak noise can be heard by the stethoscope („plup“)
- switch the watch off when you hear the sound

Result
time 1 - solid food (normal transport time 6 -12s )
time 2 - liquid food (normal transport time 2 - 6 s)

Conclusion: are the results normal?
Protein digestion

**Stomach**
- pepsin
- chymosin

**Pancreatic juice** (released into small intestine)
- trypsin
- chymotrypsin
- carboxypeptidase

**Small intestine** (brush border of enterocytes)
- aminopeptidases

**Proteins**

**polypeptides, peptides**

**dipeptides, tripeptides, amino acids**

Absorption by secondary active transport (sodium co-transport)

blood
Fat digestion

Stomach
- gastric lipase – milk fat only

Small intestine
- pancreatic juice (pancreatic lipase)
- bile (no enzymes)
- intestinal juice (intestinal lipase)

fatty acids, glycerol monoglycerides

- formation of micelles (particles containing bile acid salts, monoacylglycerols, fatty acids, cholesterol, phospholipids, lecithin)

Fat absorption
- passive diffusion through the cell membrane into blood or lymphatic vessels
Carbohydrate digestion

Oral cavity
salivary \( \alpha \)-amylase

Small intestine
pancreatic juice
• \( \alpha \)-amylase

Small intestine
brush border
- enterocytes

- maltase

Absorption:
- glucose - secondary active transport (sodium co-transport)
- fructose – facilitated diffusion

starch
polysaccharide

sacharose
disaccharide

lactose
disaccharide

-glucose
-fructose
-galactose

monsacharides
in food
Absorption

- transport of the digestion products into mucosal cells, then into blood or lymph

**Oral cavity, stomach**
- mucosa is not adapted for absorption - small surface area
- food insufficiently digested
- a few fat-soluble substances can be absorbed here in small quantities

**Small intestine**
- maximum absorption (mainly duodenum and jejunum)
- increase in absorptive surface area (Kerckring’s folds, villi, microvilli)
- products of digestion of proteins, fats, carbohydrates + electrolytes, vitamins

**Large intestine** – absorption of water, electrolytes, vitamins
Mechanisms of absorption

1. Passive transport (in concentration gradient)
   a/ Simple diffusion
   b/ Facilitated diffusion

2. Active transport (against concentration gradient)
   a/ Primary active transport
   b/ Secondary active transport (cotransport)
   c/ Pinocytosis
Glycaemia

- human body tightly regulates the blood glucose level as a part of metabolic homeostasis

Glycaemia

• normal fasting blood level: 3.6 to 5.6 mmol/L
• temporary rises after meal
• peaks approximately 60 min after the start of a meal, does not exceed 7.8 mmol/L (in non-diabetics)
• returns to preprandial levels (levels before meal) within 2–3 hours

Oral glucose tolerance test (oGTT)

- standardized amount of glucose (75 g) is administered to an examinee
- the zero time blood sample (before giving of glucose) is analyzed for glucose level
- the 2nd hour sample is analyzed for the glucose level
Task: Determination of glycaemia by glucometer

-Aim of the task

a/ to determine the baseline (fasting) glucose level (= zero blood sample)

b/ to perform the oral glucose tolerance test (oGTT)

a standardized amount of glucose (75 g) is administered to the examinee

a simple screening requires measurement of

- glycaemia before administration of glucose = task a/
- glycaemia in 2 hours after administration of glucose = task b/
Procedure

• disinfect and puncture the tip of the 4th finger
• sweep away the first drop of blood, use the next drops for analysis
• switch on the glucose meter by inserting the test strip (after puncturing !!!)
• gently touch the channel of the test strip to the blood drop.
• blood will be drawn into the strip and the confirmation window will fill completely

• move the test strip away from the blood drop
• wait for the glucometer to count down from 5 to 1
• read the result on the display of the glucometer
• turn off the glucometer by removing the strip
• the examinee drinks within 5 minutes a glucose solution (75 g of glucose in 150 – 200 mL of water)
• exactly 2 hours after the examinee began to drink the glucose solution measure the glycaemia again

Report
Write down the results:
- fasting glycaemia (mmol/L)
- glycaemia 2 hours after glucose administration (mmol/L)

Use the following table and write down evaluation of the results

Reference values for evaluation of glycaemia (mmol/L)

<table>
<thead>
<tr>
<th></th>
<th>Normal values</th>
<th>Impaired fasting glycaemia</th>
<th>Impaired glucose tolerance</th>
<th>Diabetes mellitus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting glycaemia</td>
<td>&lt; 5.6</td>
<td>5.6 – 6.9</td>
<td>5.6 – 6.9</td>
<td>≥ 7.0</td>
</tr>
<tr>
<td>Glycaemia 2 h after glucose administration</td>
<td>&lt; 7.8</td>
<td>&lt; 7.8</td>
<td>7.8 – 11.0</td>
<td>≥11.1</td>
</tr>
</tbody>
</table>
Physiological properties of the smooth muscle in antrum pylori (PC programme)
Control of the Digestive System
(control of motility, secretion, blood flow, absorption)

Digestive system is controlled by:
1. automatic activity – local control
2. autonomic nerves
3. hormones

1. local control of GI system

- function of enteric nervous system
  A. plexus submucosus
    - controls secretion of glands in mucosa and blood flow
  B. plexus myentericus
    - controls motility – frequency and strength of smooth muscle contraction, tone of smooth muscles
2. Nervous regulation of GI functions by autonomic NS

- the function of the ENS can be modified by the autonomic nervous system (ANS)

- neurotransmitters released from nerve terminals binds to specific binding sites \textit{(receptors)} in the effector organs

- the binding action initiates a series of specific biochemical reactions in the target cells that produce a physiological response.
**Parasympathetic nervous system** - increases GI activity (rest and digest)
- ↑ motility, blood flow, secretion, open valves in GI system
- neurotransmitter: **acetylcholine**
- receptors: muscarinic, nicotinic
- **parasympathetic agonists** (**parasympathomimetics**) - substances whose effects are similar to those resulting from stimulation of the parasympathetic nervous system
- **parasympathetic antagonists** (**parasympatholytics**) – drugs that block the effects of the parasympathetic NS, e.g. by occupying the receptors

**Acetylcholine**  
(or parasympathomimetic)

**Lytic** – occupies the receptors
**Sympathetic nervous system** – inhibits GI activity (fight and flight)
- ↓ motility, blood flow, secretion
- neurotransmitter: norepinephrine
- sympathetic receptors: $\alpha$, $\beta$ (activation of each causes partially different effects)

- **sympathetic agonists (sympathomimetics)** - drugs that activate adrenergic receptors (either $\alpha$ or $\beta$ receptors, or both) and cause physiological effects similar to effects of the sympathetic NS

- **sympathetic antagonists (sympatholytics)** - are drugs that block the effects of the sympathetic NS, e.g. by occupying the receptors
Task: Physiological properties of the smooth muscle in antrum pylori (computer programme)

- observe and record the effect of substances influencing the autonomic nervous system on activity of the smooth muscle (in digestive system)

Basal activity
- frequency of contractions
- intensity of contractions

Increased activity
- ↑ frequency
- ↑ strength

Decreased activity
- ↓ frequency
- ↓ intensity

Increased activity
- ↑ frequency
- ↑ strength
- ↑ tone
• Start the programme Sim Vessel
• Choose the option Practical course
• Hang on the muscle strip (pyloric antrum) on the hanger
• Hang the 2 weights in the hook (2x50 mg)
• Switch the power on (the record will start)
• Click the button next to „Zero adjust“ (the line should be recorded in the middle of paper)
• Adjust the settings: Speed 2cm/min Resolution 2 mV/Div
  Clock -factor 4 (click on the right icon)

Test the effect of the following substances on the gastric smooth muscle
- Choose a tube with a substance, drag it and drop under the tube (use concentration 10-2)

<table>
<thead>
<tr>
<th>Substance (s)</th>
<th>Describe the effect (change in frequency or amplitude of contractions, muscle tone)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acetylcholine</strong> (parasympathetic neurotransmitter)</td>
<td></td>
</tr>
<tr>
<td><strong>Atropine</strong> (parasympatholytic)</td>
<td></td>
</tr>
<tr>
<td><strong>Norepinephrine</strong> (sympathetic) neurotransmitter</td>
<td></td>
</tr>
<tr>
<td><strong>Norepinephrine followed by phentolamine</strong> (alpha - sympatholytic)</td>
<td></td>
</tr>
<tr>
<td><strong>Norepinephrine followed by propranolol</strong> (beta - sympatholytic)</td>
<td></td>
</tr>
</tbody>
</table>