Physiology of the digestive system

Contents

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
Layers of the intestinal wall

**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)

1. 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 (to-and–fro movements)
- contractions of the longitudinal muscle - support mixing of the chyme
2. Propulsion
- 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 muscle reacts by:
  1. contraction behind the bolus
     (prevents squeezing in backward direction)
  2. relaxation in front of the bolus
     (allows the bolus to propel)

- peristalsis proceeds as a wave in frontal direction

- in interdigestive periods - basic peristaltic activity – slow
Digestive juices - characteristics and function

- fluids produced in glands in the mucosa of GI organs or outside the digestive system (salivary glands, pancreas, liver)

- contain digestive enzymes – break down food into small, soluble and absorbable molecules

- create optimal environment for digestion (liquid environment, pH)

- their components play role in protective functions of the GIT

- basal secretion (in interdigestive period) - low
- food intake – stimulus for increased secretion

General composition of 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 and digestion
  - acts as a lubricant, makes the particles to slide 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 α-amylose)
  - 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 α - 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)
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

- 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 acid

- 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*

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

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

http://upload.wikimedia.org/wikipedia/commons/9/97/Swallow_food.png
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:ANd9GcROR85aAFFEE7XCVHVVW9aXjp0bL._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

**fats**

**Stomach**
- gastric lipase

**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 α-amylase

Small intestine
pancreatic juice
  • α-amylase

Small intestine
brush border - enterocytes

starch
polysaccharide

maltose

sacharose
disaccharide

lactose
disaccharid

Absorption:
- glucose - secondary active transport (sodium co-transport)
- fructose – facilitated diffusion
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 od 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** (**receptors**) in the effector organs

- the binding action initiates a series of specific biochemical reactions in the target cells that produce a physiological response.

![Diagram of synaptic transmission](image-url)
Parasympathetic nervous system - increases activity (rest and digest)

- ↑ motility, blood flow, secretion, open valves in GI system
- neurotransmitter: acetylcholine
- receptors: muscarinic, nicotinic
- parasympathomimetics - agents whose effects mimic those resulting from stimulation of the parasympathetic nervous system
- parasympatholytics – are drugs that block the effects of the parasympathetic NS, e.g. by occupying the receptors
**Sympathetic nervous system** – inhibits activity (fight and flight)
- ↓ motility, blood flow, secretion
- neurotransmitter **norepinephrine**
- sympathetic receptors: α, β
  - activation of each causes partially different effects

- **sympathomimetics** - drugs that activate adrenergic receptors (either α or β receptors, or both) and cause physiological effects similar to effects of the sympathetic NS
- **sympatholytics** - are drugs that block the effects of the sympathetic NS, e.g. by occupying the receptors

![Diagram showing the interaction between Norepinephrine (or symathomimetic) and receptors](image)
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)
• Start the programme Sim Vessel
• Choose the option Practical course
• Hang on the muscle strip (pyloric antrum) on the hanger
• Adjust the settings:
  - Power ON
  - Clock -factor 4 (click on the right icon)
  - Speed 2cm/min
  - Resolution 2 mV/Div

Test the effect of the following substances on the gastric smooth muscle

<table>
<thead>
<tr>
<th>Substance (s)</th>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norepinephrine (sympathetic neurotransmitter)</td>
<td>$10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Norepinephrine followed by phentolamine (alpha - sympatholytic)</td>
<td>$10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Norepinephrine followed by propranolol (beta - sympatholytic)</td>
<td>$10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Acetylcholine (parasympathetic neurotransmitter)</td>
<td>$10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Atropine (parasympatholytic)</td>
<td>$10^{-5}$</td>
<td></td>
</tr>
</tbody>
</table>