Monogastric Digestive System

**Species**

- Cow
- Pig
- Kangaroo
- Sheep
- Horse
- Dog
- Chicken

**Digestive System**

- Ruminant
- Monogastric
- Pre-gastric Fermentation
- Post-gastric Fermentation
- Herbivore
- Carnivore
- Omnivore

**Answers**

1. Cow - Ruminant, Pre-gastric, Herbivore
2. Pig - Monogastric, Post-gastric, Omnivore
3. Kangaroo - Monogastric, Pre-gastric, Herbivore
4. Sheep - Ruminant, Pre-gastric, Herbivore
5. Horse - Monogastric, Post-gastric, herbivore
6. Dog - Monogastric, post-gastric, carnivore
7. Chicken - Monogastric, Post-gastric, Omnivore

**Basic Organization**

1. Mouth
2. Esophagus
3. Stomach
4. Small intestine
5. Large intestine
6. Anus

**Associated Structures**
A. Pancreas
B. Liver
C. Gallbladder
d. Salivary glands

**Structures in Mouth**
A. Lips
B. Teeth
C. Tongue
d. Salivary glands

**Monogastric Teeth**

- Function:
  1. Mechanically reduce particle size
  2. Increase surface area

- types:
  A. Incisors are used for cutting
  B. Canine (fangs, eye teeth, tusks) are tearing teeth
  C. Premolars and molars (cheek teeth) grind the food

**Monogastric Tongue**

Function:

1. Comprised of three muscles
2. Maneuvers food in the mouth
   - Moves feed to teeth for grinding and to the back of the mouth for swallowing
3. Can distinguish between feed and toxins by papillae or taste buds

**Salivary Glands**

<table>
<thead>
<tr>
<th>Gland</th>
<th>Type of secretion</th>
<th>Main constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parotid</td>
<td>Serous</td>
<td>Water, enzymes, ions</td>
</tr>
<tr>
<td>Submaxillary</td>
<td>Mucous or mixed</td>
<td>Mucin (mucous), mucin plus enzymes (mixed), water</td>
</tr>
<tr>
<td>Sublingual</td>
<td>Mucous or mixed</td>
<td>Mucin (mucous), mucin plus enzymes (mixed), water</td>
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- Functions of Saliva
  1. Moisten feed (salt and water)
  2. Lubrication (aids swallowing)
  3. Starch and(or) lipid digestion (amylase and(or) lipase)

**Monogastric Salivary Glands**

- Flow rate affected by:
  1. Parasympathetic nervous system
     A. Increased tone = Increased flow
     B. Increased flow = Increased dilution
  2. Sympathetic nervous system
     A. Increased tone = Decreased flow
     B. Decreased flow = Increased concentration

- Volume of saliva
  1. 1 - 1.5 L/d man and pig
  2. 7 - 10 L/d horse
Monogastric Esophagus

1. Transport of food from mouth to stomach
2. Uses peristaltic contractions (wave contractions)
3. Horse/Pig:
   a) Striated muscles for first 2/3
   b) Smooth muscles for last 1/3
   c) In horse, esophagus joins stomach at an oblique angle and cardiac sphincter (the valve between the stomach and esophagus) only allows one-way flow
      ❖ MOST horses cannot belch out gas or vomit
4. Dog:
   Striated muscles throughout allow GREAT control of digesta movement both directions

Deglutition (Swallowing)

1. Reflex initiated by presence of food in pharynx
2. Propulsion of food to stomach by esophageal peristalsis

Gastric Digestion

❖ Functions

1. Reservoir for controlled release of digesta to small intestine
   ❖ Horse has small capacity – requires increased number of smaller sized meals
2. Mixing food
3. Mechanical breakdown of feed
4. Hydrolytic digestion by acid and enzymes
   ❖ Mainly protein
5. Kill bacteria
6. Secrete intrinsic factor: needed for vitamin B₁₂ absorption
7. Hormone production
**Stomach Regions**

1. Esophageal
   - Non-glandular
2. Cardiac
   - Secretes mucus
3. Fundic
   - Parietal cells
   - Chief cells
4. Pyloric
   - Mucus

**Gastric Pits**

1. Formed by numerous folds in the epithelium
2. Glands empty into the gastric pit
3. Many types of glands may empty into one gastric pit

Gastric Glands

<table>
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<tr>
<th>Gland</th>
<th>Type of secretion</th>
<th>Main constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardia</td>
<td>Mucous</td>
<td>Mucin</td>
</tr>
<tr>
<td>Pylorus or Antrum</td>
<td>Mucous</td>
<td>Mucin</td>
</tr>
<tr>
<td>Fundus</td>
<td>Enzyme acid</td>
<td>Pepsinogen, Pepsin, HCl, intrinsic factor</td>
</tr>
<tr>
<td>Chief cells</td>
<td>Acid</td>
<td></td>
</tr>
<tr>
<td>Parietal cells</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Stomach Secretions**

1. HCl
   a) Decreases pH (~2-3)
   b) Denatures protein
   c) Kills bacteria
   d) Activates pepsinogen

2. Mucus
   a) Protects lining from acid and enzymes
      - No “autodigestion”
   b) Lubricant

3. Pepsinogen
   a) Activated form is pepsin
   b) Hydrolyzes protein

4. Rennin (abomasum)
   Clots milk

5. Lipase
   Some species

**Gastric Motility and Emptying**

1. Motility aids mixing, mechanical and hydrolytic reduction of feed to chyme
   - acid pulp

2. Emptying is stimulated by distension of antral wall and presence of liquid chyme

Control of Gastric Secretions and Gastric Motility

1. Cephalic phase
2. Gastric phase
3. Intestinal phase

**Cephalic Phase**

Vagal reflex

- a) Parasympathetic innervation
- b) Increases gastric motility, enzyme secretion
- c) Small increase in HCl secretion

**Gastric Phase**

1. Local reflex, depends on presence of feed in stomach
2. Mainly mediated by gastrin
   - Increases HCl secretion

**Intestinal Phase**

1. Stimulated by duodenal distension, pH, osmolarity, nutrients (fat)
2. Pancreozymin-cholecystokinin (PZ-CCK) is released by the small intestine
   - Decreases HCl secretion and gastric motility

**Gastrointestinal Hormones**

1. Gastrin
   - a) Origin: Stomach, Abomasum
   - b) Stimulus: Food in stomach
   - c) Function: Stimulates HCl & pepsinogen secretion, increases stomach motility

2. Secretin
   - a) Origin: Duodenum
   - b) Stimulus: Acid
   - c) Function: Stimulates pancreatic secretions. Slows stomach motility and acid production
3. Cholecystokinin (CCK)
   a) Origin: Duodenum
   b) Stimulus: Fat & protein in duodenum
   c) Function: Stimulates bile and pancreatic secretions
      ❖ Also regulates appetite and feed intake

4. Gastric Inhibitory Protein (GIP)
   a) Origin: Duodenum
   b) Stimulus: Fats and bile
   c) Function: Inhibit stomach motility and secretion of acid and enzymes

**Small Intestine**

- Composed of 3 segments (proximal to distal)
  1. Duodenum
     a) Releases bile and pancreatic secretions
     b) Active site of digestion
  2. Jejunum
     a) Active site of nutrient absorption
  3. Ileum
     a) Active site of nutrient absorption
        ❖ Most water, vitamins & minerals
     b) Some bacterial presence
        ❖ Fermentation

★ The pH of the small intestine increases towards 7.0 as food moves from the duodenum to the ileum

Specialized Cells Lining Villi

1. Absorptive epithelial cell
a) Contain brush border on lumen/apical side

b) Brush border:
   - Enzymes
   - Nutrient transport molecules

2. Goblet cell
   Secretes mucus

3. Endocrine cell
   Secretes hormones into bloodstream or local cells

4. Paneth cell
   Secretory granules with anti-microbial properties

**Small Intestine – Absorptive Surface**

1. Villi
2. Enterocyte
3. Brush border
4. Cell migration from crypts to tips of villus
   - 2-3 days

**Small Intestine – Structure**

1. Lumen
2. Mucosa
3. Villi
4. Crypts
5. Lacteal
6. Enterocyte
7. Brush border
Increased Surface Area in Small Intestine for Absorption

<table>
<thead>
<tr>
<th>Structure</th>
<th>Description</th>
<th>Increase in surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plicae circularis</td>
<td>Regular ridges in small intestine</td>
<td>3x</td>
</tr>
<tr>
<td>Villi</td>
<td>Finger-like projections on mucosal (inner) surface</td>
<td>10x</td>
</tr>
<tr>
<td>Microvilli</td>
<td>1 um projections on surface of epithelium</td>
<td>20x</td>
</tr>
</tbody>
</table>

**Nutrient Absorption in the Small Intestine**

1. Principal site of absorption of amino acids, vitamins, minerals and lipids
   - Glucose and other sugars in monogastrics
2. Generally, most absorption occurs in the proximal (upper) part of the small intestine but some absorption occurs in all segments
   - Duodenum, jejunum and ileum
3. Digestion and absorption within SI is rapid
   - Within 30 minutes of entering SI

**Nutrient Absorption**

- Variety of mechanisms
  1. Diffusion
  2. Facilitated diffusion
  3. Active transport
  4. Pinocytosis or endocytosis

- Dependent upon
  1. Solubility of the nutrient (fat vs. water)
  2. Concentration or electrical gradient
  3. Size of the molecule to be absorbed
**Diffusion**
1. Water and small lipid molecules pass freely through membrane
2. Move down concentration gradient to equalize concentrations

**Facilitated Diffusion**
1. Carrier loads particle on outside of cell
2. Carrier releases particle on inside of cell
3. Reverse

Allows equalization of concentrations across membrane

**Active Transport**
1. Carrier loads particle on outside of cell
2. Carrier releases particle on inside of cell
3. Carrier returns to outside to pick up another particle
   - Unidirectional movement
   - Transports nutrients against concentration gradient

**Pinocytosis or Endocytosis**
1. Substance contacts cell membrane
2. Membrane wraps around or engulfs substance into sac
3. Sac formed separates from the membrane and moves into cell

**Secretions Entering SI**
1. Intestinal mucus
2. Brush border enzymes
3. Pancreatic juices
   - Produced & stored in pancreas
4. Bile
a) Produced in liver
b) Stored in gallbladder
c) Horse has no gallbladder
   - Direct bile secretion into duodenum
   - Cannot store bile—continuous intake of food

**Intestinal Mucus**

1. Secreted by glands in wall of duodenum
   - Brunner’s glands
2. Acts as lubricant and buffer to protect duodenal wall

**Primary Enzymes for Carbohydrates**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Enzyme</th>
<th>Origin</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch, glycogen,</td>
<td>Amylase</td>
<td>Saliva &amp; pancreas</td>
<td>Maltose &amp; Glucose</td>
</tr>
<tr>
<td>dextrin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maltose</td>
<td>Maltase</td>
<td>SI</td>
<td>Glucose</td>
</tr>
<tr>
<td>Lactose</td>
<td>Lactase</td>
<td>SI</td>
<td>Glucose &amp; galactose</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Sucrase</td>
<td>SI</td>
<td>Glucose &amp; fructose</td>
</tr>
</tbody>
</table>

**Primary Enzymes for Proteins**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Enzyme</th>
<th>Origin</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk protein</td>
<td>Rennin</td>
<td>Gastric mucosa</td>
<td>Curd</td>
</tr>
<tr>
<td>Proteins</td>
<td>Pepsin</td>
<td>Gastric mucosa</td>
<td>Polypeptide</td>
</tr>
<tr>
<td>Polypeptides</td>
<td>Trypsin,</td>
<td>Pancreas</td>
<td>Peptides</td>
</tr>
<tr>
<td></td>
<td>Chymotrypsin</td>
<td>Pancreas</td>
<td>Peptides</td>
</tr>
<tr>
<td>Peptides</td>
<td>Carboxypeptidase, Aminopeptidase</td>
<td>Pancreas, Small intestine</td>
<td>Peptides &amp; amino acids</td>
</tr>
</tbody>
</table>
### Primary Enzymes for Lipids

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Enzyme</th>
<th>Origin</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipids</td>
<td>Lipase &amp; colipase</td>
<td>Pancreas</td>
<td>Monoglycerides &amp; free fatty acids</td>
</tr>
</tbody>
</table>

### Bile
1. Green, viscous liquid
   - Alkaline pH (neutralize acidic chyme)
2. Secreted by liver via bile duct to duodenum
   - Stored in gall bladder (except in horses)
3. Functions to emulsify fats
4. Composition
   - a) Bile salts (glycocholic and taurocholic acids)
   - b) Bile pigments (bilirubin and biliverdin)
   - c) Cholesterol
5. 95% reabsorbed and returned to liver
6. NOT AN ENZYME

### Pancreatic Juice
1. Clear, watery juice
2. Enters duodenum via pancreatic duct
3. Aids in fat, starch, and protein digestion
4. Contains
   - a) $\text{HCO}_3^-$
b) Trypsinogen

c) Chymotrypsinogen

d) Procarboxypeptidase

e) Amylase

f) Lipase

g) Nuclease

**Importance of Pancreas for Digestion**

1. Produces enzymes responsible for
   a) 50% of carbohydrate digestion
   b) 50% of protein digestion
   c) 90% of lipid digestion

2. Produces sodium bicarbonate for neutralization of chyme in duodenum

**Activation of Pancreatic Enzymes**

1. Enterokinase
   a) Secreted from crypts in duodenum
   b) Trypsinogen → trypsin

2. Trypsin then converts:
   a) Trypsinogen → trypsin
   b) Chymotrypsinogen → chymotrypsin
   c) Procarboxypeptidase → carboxypeptidase

Digestive Enzymes

a) Stomach

1. Pepsinogen

2. Chymosin (rennin)
b) Pancreas
   1. Trypsinogen
   2. Chymotrypsinogen
   3. Procarboxypeptidase
   4. Amylase
   5. Lipase
   6. Nuclease

c) Brush Border (SI)
   1. Sucrase
   2. Maltase
   3. Lactase
   4. Aminopeptidase
   5. Dipeptidase
   6. Enterokinase

**Large Intestine**

a) Composed of three segments
   1. Cecum
   2. Colon
   3. Rectum

b) Function
   1. Fermentative digestion
      - No enzyme secretion
      - Relies on microbes or secretions washed out of the SI
   2. Absorption of remaining water, volatile fatty acids (VFAs) from microbial fermentation and minerals
3. **Digesta storage**

Degree of development is species dependent

**Monogastric Large Intestine**

- **Function:**
  1. Absorption of liquid
  2. Mass movements move fecal matter to anus
  3. Usually only a few times a day
     - Associated with defecation

**Bacteria**

- a) Cellulolytic – digest cellulose (forages)
- b) Amylolytic – digest starches and sugars (concentrates or grains)
- c) Other types:
  1. Proteolytic
     - Clostridium
  2. Organic acid utilizers
  3. Methanogens
     - Produce CO₂, H₂, formate, CH₄

**Rectum**

- Muscular area of large intestine used for storage of feces and ultimately for defecation

  Feces includes sloughed cells, undigested food and microbial matter

**Avians (Poultry)**

**Esophagus**

- Enlarged area called crop
  1. Ingesta holding and moistening
2. Location for breakdown of carbohydrate by amylase
3. Fermentation

**Proventriculus (stomach)**

1. Release of HCl and pepsin (gastric juices)
2. Ingesta passes through very quickly (14 seconds)

**Gizzard (ventriculus)**

- Muscular area with a hardened lining reduces particle size
  1. Muscular contractions every 20-30 seconds
  2. Includes action of grit
  3. HCl and pepsin secreted in proventriculus

**Small intestine**

1. Similar to other monogastrics
2. No Lacteals

**Ceca and large intestine**

1. Contain two ceca instead of one as in other monogastrics
2. Large intestine is very short (2-4 in) and empties into cloaca where fecal material will be voided via the vent
   a) Water resorption
   b) Fiber fermentation by bacteria
   c) H$_2$O soluble vitamin synthesis by bacteria