I. Digestion of carbohydrates: overview

A. Oral digestion
   1. Ingested starch is hydrolyzed by α-amylase.
   2. pH optimum is 6.7.

B. Stomach
   1. Salivary amylase digestion continues.
   2. Some fermentation of lactose to lactic acid can occur.

C. Intestinal luminal digestion
   1. Pancreatic α-amylase digests starch to maltose.
   2. Branched-chain limit dextrins also are formed.

D. Intestinal mucosal digestion
   1. Lactase, trehalase, and four maltases work on oligosaccharides.
   2. Monosaccharides are absorbed into the enterocytes.

E. Poultry (avian species in general)
   1. The crop, proventriculus, and gizzard replace the simple stomach of other monogastrics.
   2. The esophagus extends to the cardiac region of the proventriculus.
   3. The proventriculus is similar to the stomach, in that typical gastric secretions (mucin, HCl, and pepsinogen) are produced.
II. The gastrointestinal tracts of pigs and poultry

B. Architecture and secretions of the gastrointestinal tract in nonruminant mammals

1. Oral region – In the mouth, saliva is secreted from the parotid, mandibular, and sublingual glands. α-Amylase in saliva initiates carbohydrate digestion.

2. Esophageal region – The esophagus extends from the pharynx to the esophageal portion of the stomach.

3. Gastric region – The stomach is divided into the esophageal region, the cardiac region, and the fundic (proper gastric) region. The cardiac region elaborates mucus, proteases, and lipase (discussed later in the semester). The action of α-amylase stops in the fundus, when the pH drops below 3.6.

4. Pancreatic region – The endocrine portion secretes insulin and glucagon (and other peptide hormones) from the islets of Langerhans. The exocrine portion secretes pancreatic α-amylase in addition to other digestive enzymes. These and bile secretion will be discussed later.

5. Small intestine – The duodenum (4-5%) originates at the distal end of the stomach (pyloric valve), whereas the jejunum (88-91%) and ileum (4-5%) form the lower intestine. Pancreatic α-amylase is mixed with chyme from the stomach. Alkaline secretions from Brunner’s glands raise the pH to approx. 8.0

6. Large intestine – Associated with the proximal end of the large intestine is a short cecum, which is the site of microbial fermentation. The colon is long and highly functional.
C. Architecture and secretions of the gastrointestinal tract in poultry

1. Oral region – Birds lacking a soft palate (poultry) pick up food, raise their heads, and swallow. Taste buds are few in number. (Most domestic birds do not secrete amylase in their saliva.) Saliva primarily lubricates and buffers foods.

2. Esophageal region – The esophagus extends from the pharynx to the crop. The crop acts as a storage organ. The crop contains salivary amylase, and limited fermentation occurs.

3. Gastric region – The proventriculus secretes fluids similar to those in the stomach. The gizzard is the primary organ for mastication. Often contains pieces of grit.


5. Small intestine – The duodenum originates at the distal end of the gizzard, whereas the jejunum and ileum run together to form the lower intestine.

6. Large intestine – Associated with the large intestine is the cecum. The colon is extremely short and has no significant function.

FIGURE 2-2. Digestive tract of chicken. Photo by Don Helfer, Oregon State University Diagnostic Laboratory.
III. Digestion and fermentation of carbohydrates

A. Oral digestion
1. Ingested starch is hydrolyzed by $\alpha$-amylase.
2. pH optimum is 6.7.

B. Stomach digestion
1. Salivary amylase digestion continues.
2. Some fermentation of lactose to lactic acid can occur. This may contribute acidity to assist the limited HCl production in infants (important for the formation of milk clots).
3. Diets high in molasses increase fermentation in the stomach, and increase VFA production.

![Image of the intestinal wall, epithelium, and enterocytes](image-url)

**FIGURE 3.3** Structure of (a) the intestinal wall, (b) the intestinal epithelium, and (c) enterocytes. (Adapted from Moran, 1982 and Herdt, 1992.)
C. Intestinal luminal digestion
   1. Pancreatic $\alpha$-amylase digests starch to maltose, branched-chain limit dextrans, and traces of glucose.
   2. These products of digestion migrate to the mucosal surface of the duodenum following a concentration gradient.

D. Intestinal mucosal digestion
   1. Lactase, trehalase, and four maltases (including sucrase) work on oligosaccharides.
   2. Monosaccharides are absorbed into the enterocytes.
   3. Absorption takes place in the duodenum and jejunum.

E. Microbial activity in the small intestine
   1. Gut microorganisms can digest nonstarch structural carbohydrates.
   2. This is associated with a substantial amount of VFA production.

F. Large intestinal digestion and fermentation
   1. Gastrointestinal contents are retained up to 38 h in the large intestine vs less than 6 h in the stomach and small intestine.
   2. Microorganisms in the colon and cecum produce cellulases, hemicellulases, and pectinsases.
   3. Primary products are VFA (acetic, propionic, and butyric acids) and methane.

III. Absorption of monosaccharides

A. Glucose and galactose
   1. Both are transported into the enterocyte by a Na-dependent glucose transporter (Sglt1).
   2. Both then are released into the blood by a facilitated sugar transporter (GLUT2).

B. Fructose
   1. Fructose is absorbed first by a Na-independent brush border fructose transporter (GLUT5).
   2. Fructose is released into the blood by GLUT2.
B. Omnivores

1. Nonglandular region – no digestive secretions or absorption occurs.
2. Cardiac region – lined with epithelial cells that secrete mucin (prevents lining of the stomach from being digested).
3. Fundic region – contains parietal cells (secrete HCl), neck chief cells (secrete mucin), and body chief cells (secrete pepsinogen, and lipase).
B. Architecture and secretions of the gastrointestinal tract in herbivores – rabbits, horses, etc.

1. Oral region – Nonruminant herbivores extensively chew food, shredding fibrous material. Digestion of carbohydrates is initiated by α-amylase.

2. Esophageal region – The esophagus extends from the pharynx to the esophageal portion of the stomach.

3. Gastric region – The stomach is divided into the esophageal (nonglandular) region, the cardiac region, and the fundic (proper gastric) region.

4. Pancreatic region – The endocrine portion secretes insulin and glucagons (and other peptide hormones) from the islets of Langerhans. The exocrine portion secretes pancreatic α-amylase in addition to other digestive enzymes.

5. Small intestine – The duodenum originates at the distal end of the stomach, and the jejunum and ileum form the lower intestine. Pancreatic α-amylase is mixed with chyme from the stomach. As in monogastics, the microbial population starts to proliferate in the ileum and continues in the cecum and colon.

6. Large intestine – Associated with the proximal end of the large intestine is an extensive cecum. The colon is long and is another site of fermentation.
C. Architecture and secretions of the gastrointestinal tract in herbivores – true ruminants

1. **Oral region** – Ruminants masticate their food to a limited extent.

2. **Esophageal region** – In ruminants, the bolus of food can travel either to the reticulorumen, or back to the mouth (rumination).

3. **Gastric region** – The stomach is divided into four compartments, the reticulum, rumen, omasum, and abomasum (glandular stomach).

4. **Pancreatic region** – The *endocrine* portion secretes insulin and glucagons (from the Islets of Langerhans). The *exocrine* portion secretes pancreatic amylase. Both regions are less developed in ruminant species than in monogastrics.

5. **Small intestine** – The *duodenum* originates at the distal end of the abomasum, and the *jejunum* and *ileum* form the lower intestine.

6. **Large intestine** – There is a small *cecum*, and the large intestine is considerably smaller than in nonruminant herbivores.
II. Digestion and fermentation of carbohydrates in true ruminants

A. Oral digestion
   1. Saliva (150 L/day) contains sodium bicarbonate (buffer).
   2. pH optimum is 6.7.

B. Reticulorumen
   1. Contains large populations of bacteria and protozoans.
   2. Make-up of microorganisms depends on diet (high-forage vs high-grain).
   3. Microorganism numbers peak 2 to 3 hours after a high-grain diet and 4 to 5 hours after a high-forage diet.
   4. Sugars and starches are degraded to VFA.
   5. Digestion of structural carbohydrates occurs in the extracellular compartment (hydrolysis to glucose) and intracellular compartment (formation of VFA).

C. Intestinal luminal digestion
   1. Pancreatic α-amylase digests starch to maltose, branched-chain limit dextrans, and traces of glucose.
   2. These products of digestion migrate to the mucosal surface of the duodenum following a concentration gradient.
   3. The amount of α-amylase produced by the ruminant pancreas is very low compared to monogastric animals.

D. Intestinal mucosal digestion
   1. Lactase, trehalase, and four maltases (including sucrase) work on oligosaccharides.
   2. Monosaccharides are absorbed into the enterocytes.
   3. Absorption takes place in the duodenum and jejunum.

E. Microbial activity in the small intestine
   1. Gut microorganisms can digest nonstarch structural carbohydrates.
   2. This is associated with a small amount of VFA production in ruminants.

F. Large intestinal digestion and fermentation
   1. Microorganisms in the colon and cecum produce cellulases, hemicellulases, and pectinsases.
   2. Primary products are VFA (acetic, propionic, and butyric acids) and methane. This is limited in ruminants.