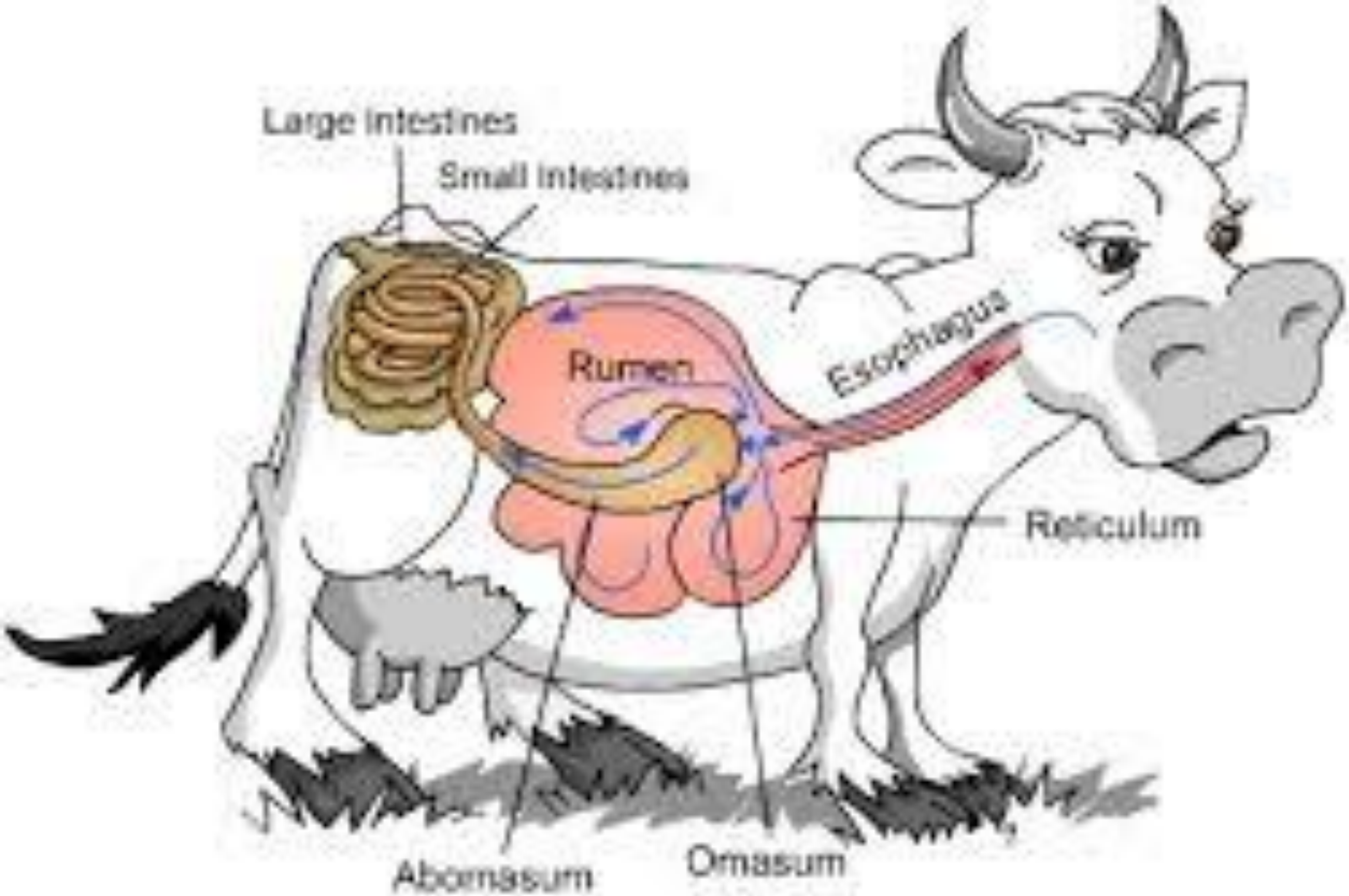
RUMEN PHYSIOLOGY



4 Chamber Stomach of a Ruminant

Herbivorous Strategies

- •**Cranial fermentors** or **ruminants** have a large, multicompartmented section of the digestive tract between the oesophagus and true stomach. These forestomachs house a very complex ecosystem that supports fermentation.
- •**Caudal fermentors,** also known as caecal digestors, are similar to dogs and humans through the stomach and small intestine, but their large intestine, where fermentation occurs, is complex and exceptionally large. Examples of caecal digestors include horses and rabbits.
- Both employ **symbiotic** relationships.
  - Ruminant provides the environment and feed.
  - Microbes digest cellulose to provide nutrients in the form of microbial protein and volatile fatty acids.

Implications of Location:

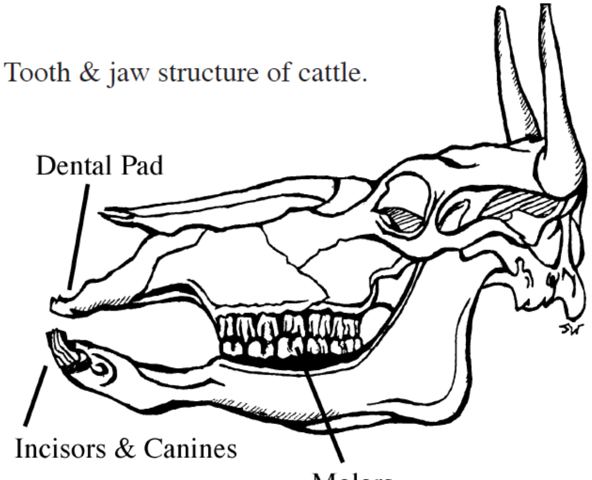
- The **positioning of the fermentation vat** in relation to the small intestine has important implications for animal's physiology and nutrition. These similarities and differences can be summarized as follows:

Function	Ruminants	Cecal Digestors
Ability to efficiently digest and extract energy from cellulose	Yes	Yes
Ability to utilize dietary hexose sources directly	No	Yes
Ability to utilize the protein from fermentative microbes	Yes	No

In ruminants, those microbes flow into the stomach and small intestine, where they are digested and absorbed as amino acids and small peptides. Because the fermentation vat of a horse is behind the small intestine, all their microbial protein is lost.

Digestive Tract of Ruminant

Figure 1. Tooth & jaw structure of cattle.



- There are **no incisors** on the top; instead cattle have a **dental pad**.
- Cattle have 6 premolars and 6 molars on both top and bottom jaws for a total **of 24 molars**.
- There is a large gap between the incisors and molars. This configuration allows cattle to harvest and chew a large amount of fibrous feed.
- Teeth are primarily for grinding. Tongues to gather grass and then pinch it off between their incisors and dental pad. Cattle cannot bite off grass very well, and they are inefficient at grazing closely. The inside of the cheeks and palate are rough which helps hold feed in while cattle chew with a side to side motion.

Ruminal Fermentation

- Fermentation is supported by a rich and dense collection of microbes. Each milliliter of rumen content contains roughly 10 to 50 billion bacteria, 1 million protozoa and variable numbers of yeasts and fungi.
- The environment of the rumen and large intestine is anaerobic .
- Almost all these microbes are anaerobes or facultative anaerobes.
- Microbes interact and support one another in a complex food web, with the waste products of some species serving as nutrients for other species. Rumen fluid normally has a pH between 6 and 7, but may fall if large amounts of soluble carbohydrate are consumed

A Flow Fermentation System

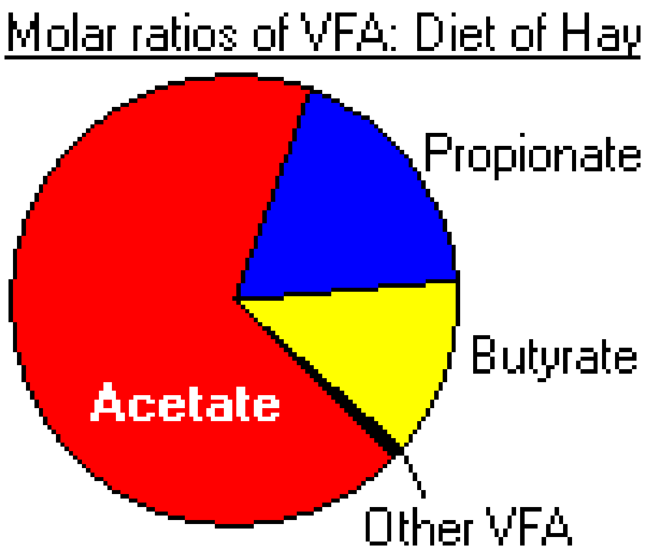
- **Synthesis of high quality protein in the form of microbial bodies**. In ruminants, bacteria and protozoa are constantly flowing into the abomasum and small intestine, where they are digested and absorbed. Fermentative microbes can synthesize all the amino acids (incl essential) and thereby provide them to their host.
- **Synthesis of protein from non-protein nitrogen sources**. Fermentative microbes can utilize urea to synthesize protein. In some situations, ruminants are fed urea as a inexpensive dietary supplement.
- **Synthesis of B vitamins**. Mammals can synthesize only two of the B vitamins and require dietary sources of the others. Fermentative microbes are able to synthesize all the B vitamins, and deficiency states are rarely encountered.

Substrates for Fermentation

- All dietary carbohydrates and proteins can serve as substrates for microbial fermentation
- Advantage of being a herbivore is the ability to efficiently extract energy from cellulose and other components of plant cell walls.
- Cellulose itself is a linear polymer of glucose molecules linked to one another by beta[1-4] glycosidic bonds
- No enzyme able to hydrolyze beta[1-4] glycosidic bonds has evolved in vertebrates.
- Bacteria and protozoa in the rumen or hindgut produce all the enzymes necessary to digest cellulose and hemicellulose.
- Glucose released in this process is then taken up and metabolized by the microbes, and the waste products of microbial metabolism are passed on to the host animal.

Products of Fermentation

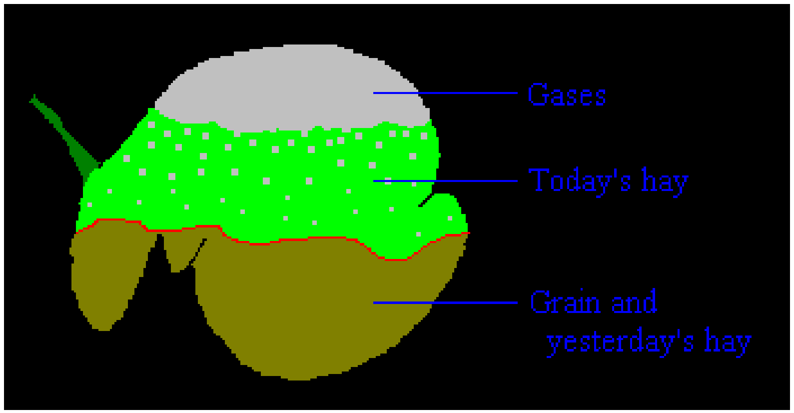
- Fermentation occurs under anaerobic conditions.
- Sugars are metabolized predominantly to volatile fatty acids (VFAs).
- The principle VFAs are acetic, propionic and butyric acids
- The ratio of these VFA's vary with
- Additional major products include lactic acid, carbon dioxide and methane



The Vat

- Well-masticated substrates are delivered through the oesophagus on a regular schedule.
- Fermentation products are either absorbed in the rumen itself or flow out for further digestion an
- Ruminants produce large quantities of saliva. Published estimates for adult cows are in the range of 100 to 150 liters of saliva per day!
- Saliva serves to lubricate and:
- provision of fluid for the fermentation vat
- alkaline buffering - saliva is rich in bicarbonate, which buffers the large quanitity of acid produced in the rumen and is probably critical for maintainance of rumen pH.
- d absorption downstream.

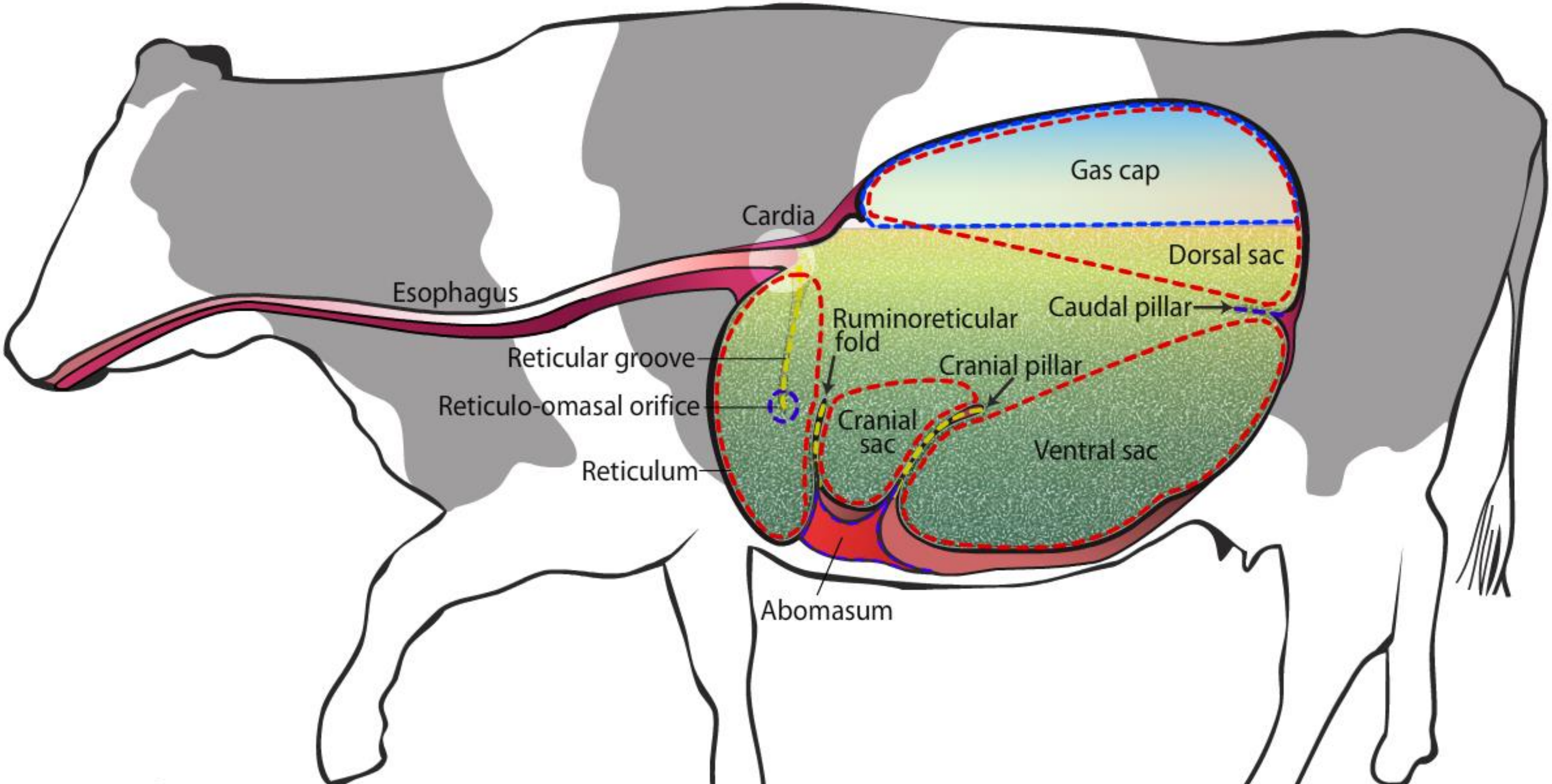
Within the Rumen



- Materials within the rumen partition into 3 zones based on their specific gravity.
- Gas rises to fill the upper regions, grain and fluid-saturated roughage ("yesterday's hay") sink to the bottom, and newly arrived roughage floats in a middle layer.
- The rate of flow of solid material through the rumen is quite slow and dependent on its size and density.

Rumen Movements

- Ruminal contractions constantly flush lighter solids back into the rumen. A cycle of contractions occurs **1 to 3 times per minute**. The highest frequency is seen during feeding, and the lowest when the animal is resting.
- The smaller and more dense material tends to be pushed into the reticulum and cranial sac of the rumen, from which it is ejected with microbe-laden liquid through the reticulo-omasal orifice into the omasum.
- An orderly pattern of ruminal motility is initiated early in life and, except for temporary periods of disruption, persists for the lifetime of the animal.
- Movements serve to mix the ingesta, aid in eructation of gas, and propel fluid and fermented foodstuffs into the omasum. If motility is suppressed for a significant length of time, ruminal impaction may result.



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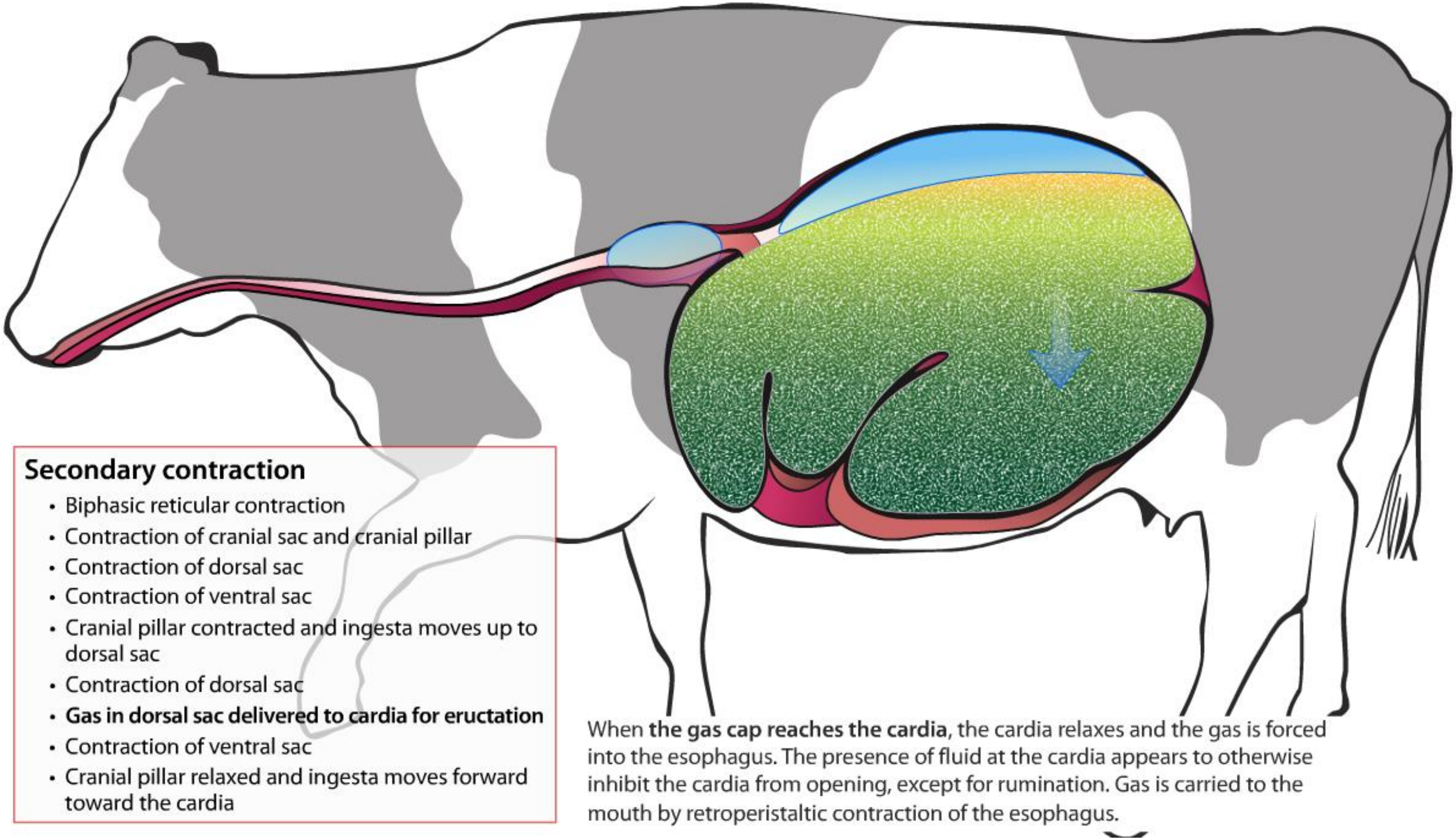
Labels **ON**

Akin to the heart, faithful contraction of the ruminant forestomach is required to sustain life. Reticulorumen motility mediates the mixing of fiber with fermentative bacteria, regulates the rate of nutrient intake and delivery, permits the offloading of ~60 liters of fermentative gases per hour, and enables these animals to eat in haste and re-masticate their food at leisure and in greater safety. An understanding of how, when and why the reticulorumen contracts is important to the assessment of ruminant health, optimal production, and in the recognition, diagnosis and treatment of ruminant disease.

Secondary (Eructation) Rumen Contraction

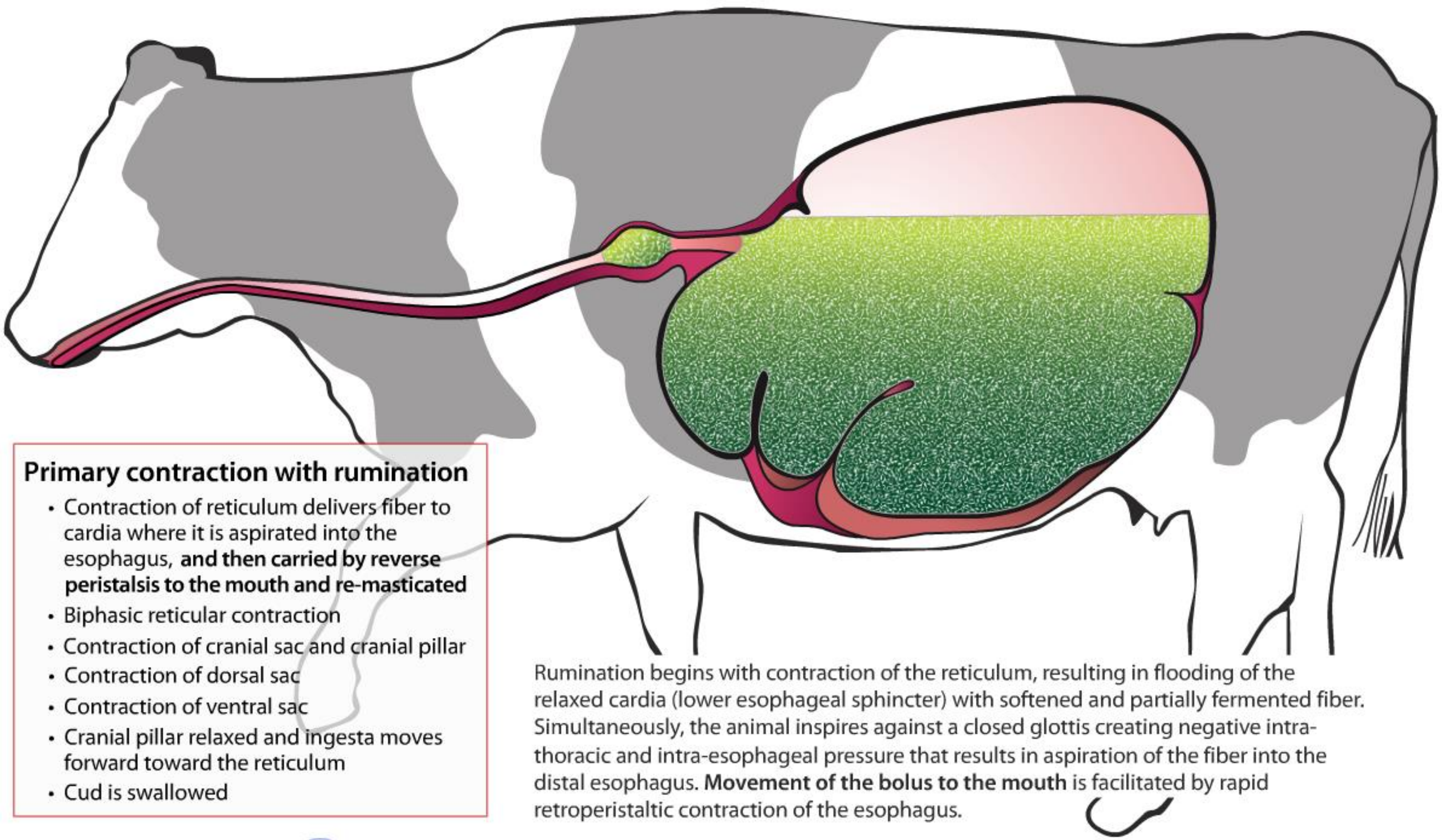


Secondary contraction

- Biphasic reticular contraction
- Contraction of cranial sac and cranial pillar
- Contraction of dorsal sac
- Contraction of ventral sac
- Cranial pillar contracted and ingesta moves up to dorsal sac
- Contraction of dorsal sac
- **Gas in dorsal sac delivered to cardia for eructation**
- Contraction of ventral sac
- Cranial pillar relaxed and ingesta moves forward toward the cardia

When **the gas cap reaches the cardia**, the cardia relaxes and the gas is forced into the esophagus. The presence of fluid at the cardia appears to otherwise inhibit the cardia from opening, except for rumination. Gas is carried to the mouth by retroperistaltic contraction of the esophagus.

Primary (Mixing) with Rumination

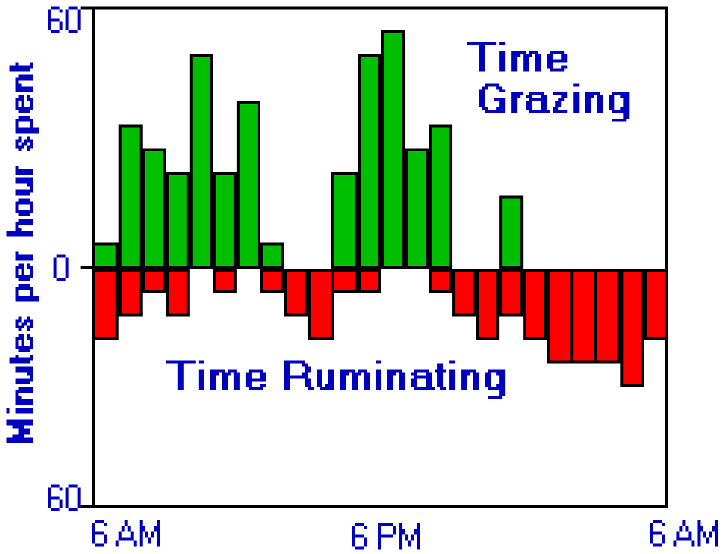


Primary contraction with rumination

- Contraction of reticulum delivers fiber to cardia where it is aspirated into the esophagus, **and then carried by reverse peristalsis to the mouth and re-masticated**
- Biphasic reticular contraction
- Contraction of cranial sac and cranial pillar
- Contraction of dorsal sac
- Contraction of ventral sac
- Cranial pillar relaxed and ingesta moves forward toward the reticulum
- Cud is swallowed

Rumination begins with contraction of the reticulum, resulting in flooding of the relaxed cardia (lower esophageal sphincter) with softened and partially fermented fiber. Simultaneously, the animal inspires against a closed glottis creating negative intra-thoracic and intra-esophageal pressure that results in aspiration of the fiber into the distal esophagus. **Movement of the bolus to the mouth** is facilitated by rapid retroperistaltic contraction of the esophagus.

- Rumination is regurgitation of ingesta from the reticulum, followed by remastication and reswallowing. It provides for effective mechanical breakdown of roughage and thereby increases substrate surface area to fermentative microbes. Rumination is involuntary. It enables fibrous material to be remasticated. Grazing cattle spend 1/3rd of their day ruminating.
- Fibrous rations encourage more rumination



Rumination occurs predominantly when the animal is resting and not eating.

Graph depicts how steers spend their day on an alfalfa pasture relative to time spent grazing and ruminating.

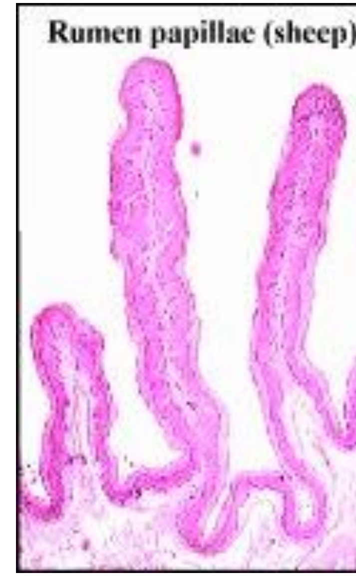
Fermentation in the rumen generates enormous, quantities of gas; 30-50 liters per hour in adult cattle and about 5 liters per hour in a sheep or goat.

Eructation or belching is how ruminants continually get rid of fermentation gases.

- As mentioned above, an eructation is associated with almost every secondary ruminal contraction
- FAO indicates that ruminants are responsible for roughly 20% of global methane emmisions, which equates to approximately 3-5% of total greenhouse gas production.

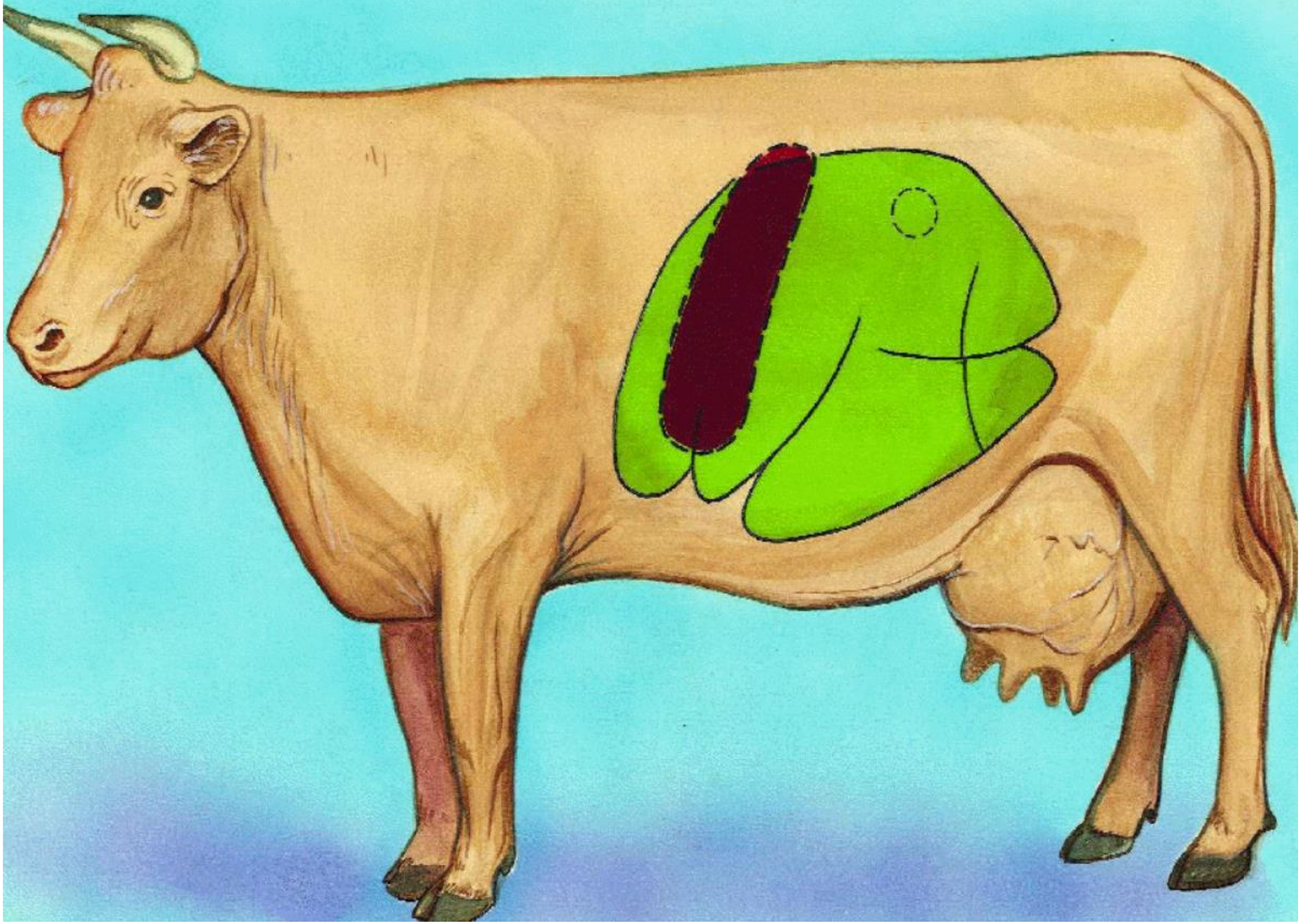
Nutrient Utilization in Rumen

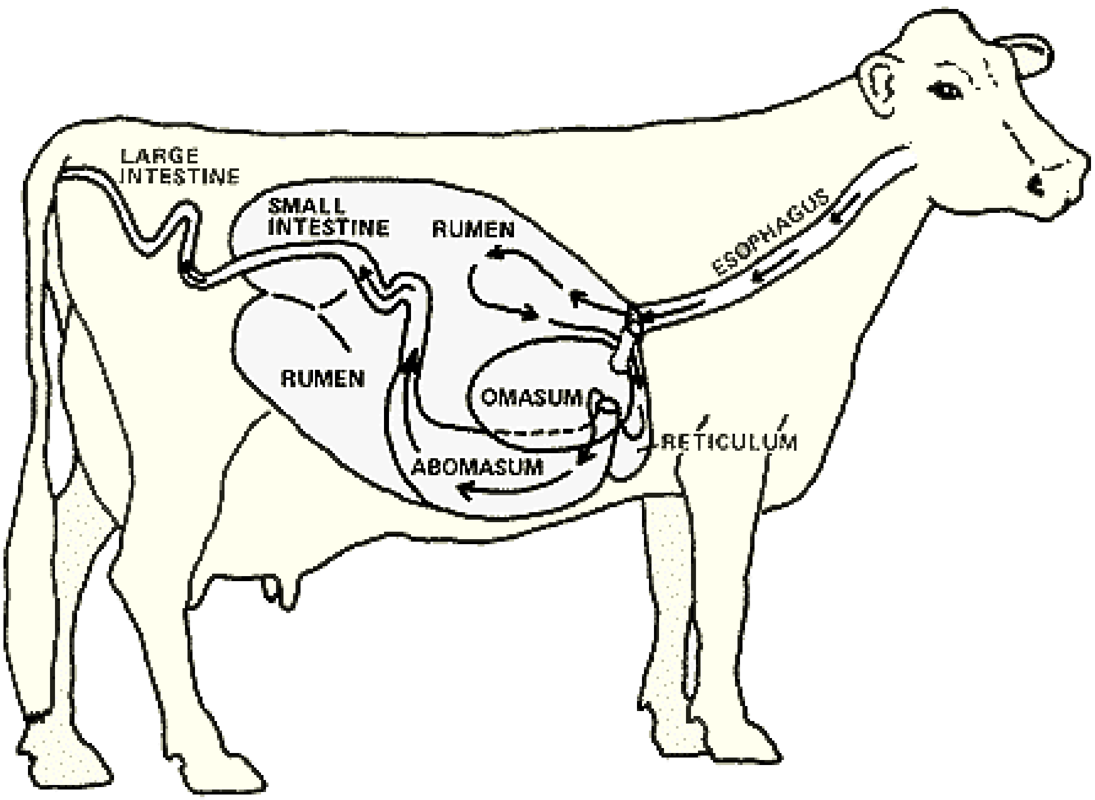
- Volatile fatty acids (VFA) are produced in large amounts through fermentation.
- VFAs provide >70% of the ruminant's energy supply.
- Virtually all of the VFAs formed in the rumen are absorbed across the ruminal epithelium, and carried by ruminal veins to the portal vein and hence through the liver.
- The rumen is lined with stratified squamous epithelium , generally not noted for efficient absorption.
- Nonetheless, this squamous epithelium performs efficient absorption of VFA, as well as lactic acid, electrolytes and water.



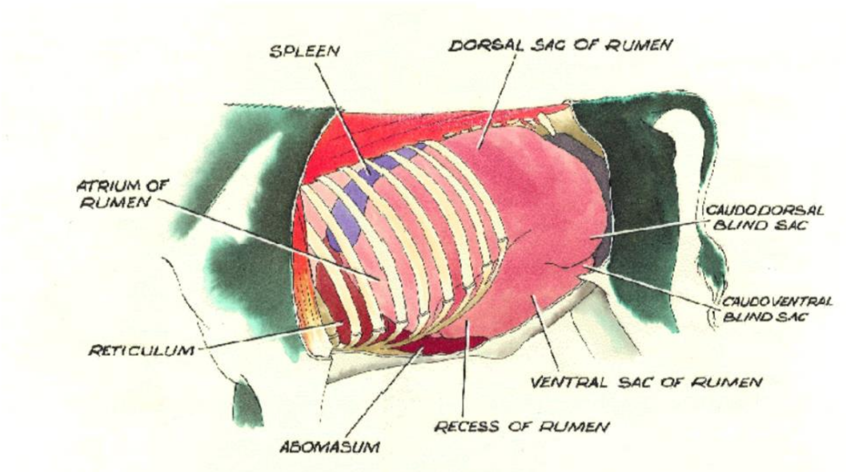
Nutrient Utilization in Rumen

- The three major VFA absorbed from the rumen have somewhat distinctive metabolic fates:
- •Acetic acid is utilized minimally in the liver, and is oxidized throughout most of the body to generate ATP. Another important use of acetate is as the major source of acetyl CoA for synthesis of **lipids**.
- •Proprionic acid is almost completely removed from portal blood by the liver. Within the liver, proprionate serves as a major substrate for **gluconeogenesis**, which is absolutely critical to the ruminant because almost no glucose reaches the small intestine for absorption.
- •Butyric acid, most of which comes out of the rumen as the ketone beta-hydroxybutyric acid, is oxidized in many tissues for **energy** production.





The digestive tract consists of the mouth, oesophagus, a complex four-compartment stomach, small intestine and large intestine.
The stomach includes the rumen , reticulum or "honeycomb," the omasum or "manyplies," and the abomasum or "true stomach."



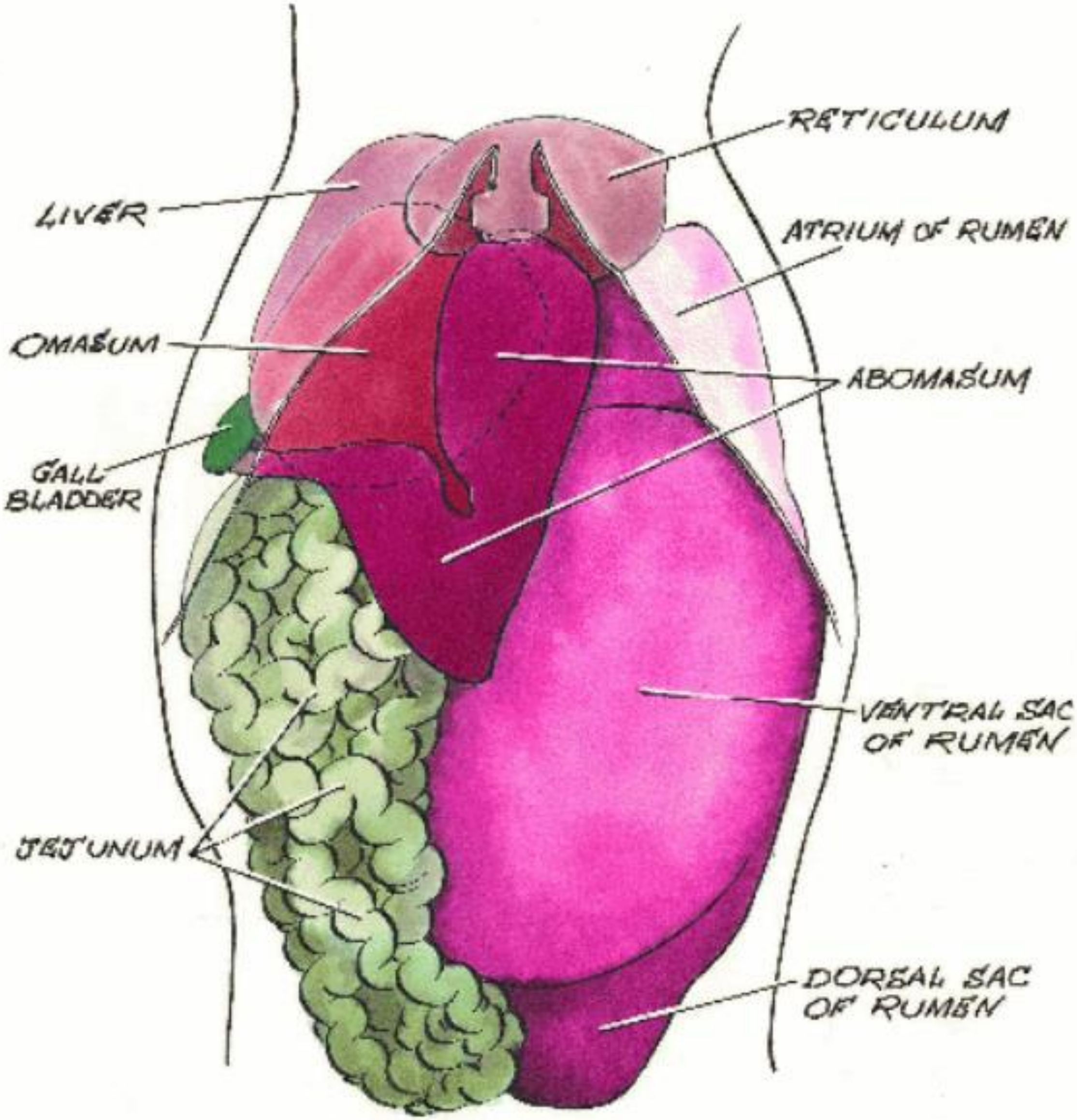
TOPOGRAPHY OF LEFT SIDE OF ABDOMEN OF 9-MONTH-OLD NON-PREGNANT HEIFER

- Collectively, these organs occupy almost 3/4ths of the abdominal cavity, filling virtually all of the left side and extending significantly into the right.
- The reticulum lies against the diaphragm and is joined to the rumen by a fold of tissue.
- The rumen, far and away the largest of the forestomaches, is itself sacculated by muscular pillars into what are called the dorsal, ventral, caudodorsal and caudoventral sacs.

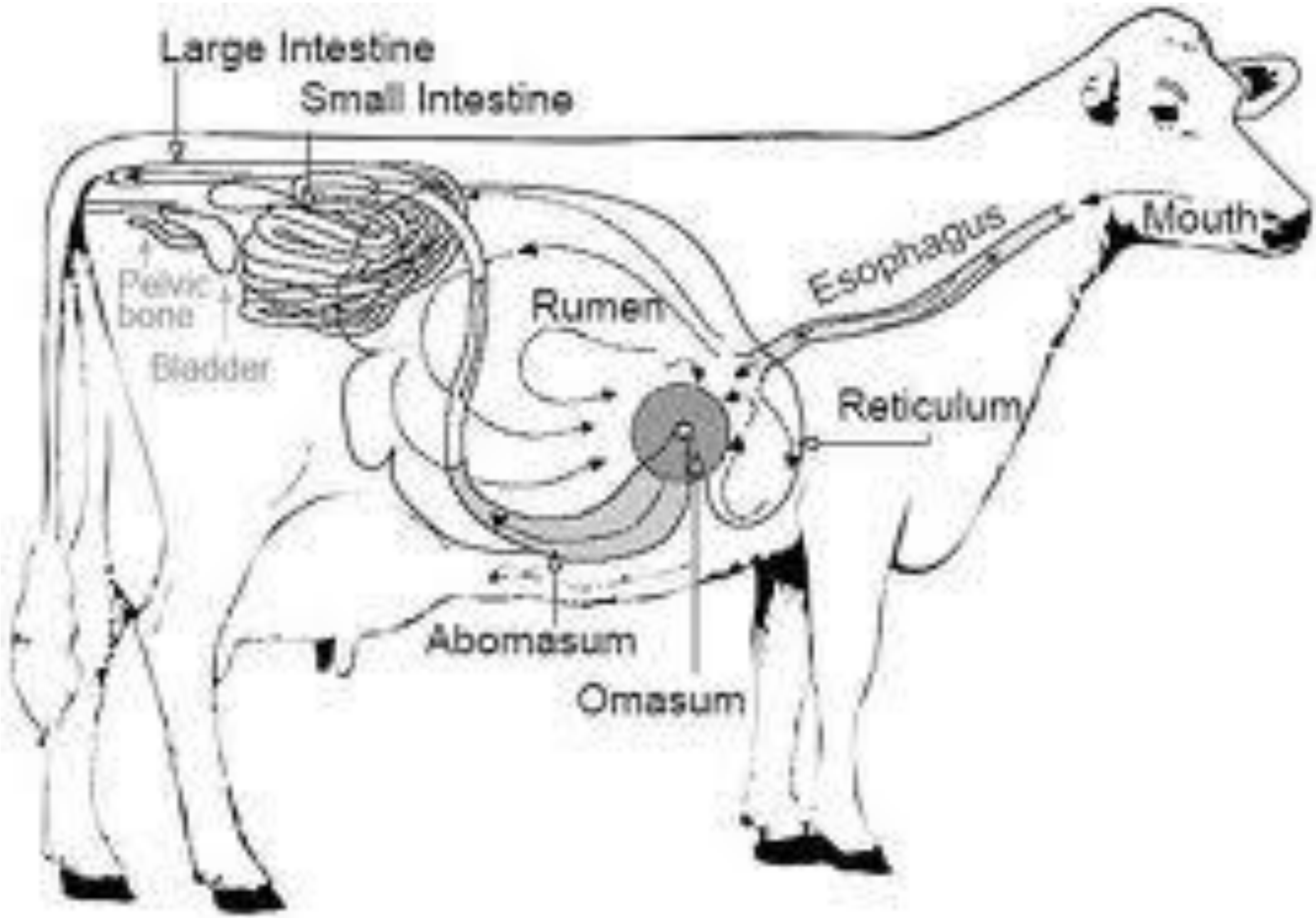
Reticulum

- Reticular epithelium is thrown into folds that form polygonal cells that give it a reticular, honey-combed appearance.
- Numerous small papillae stud the interior floors of these cells.

- The inside of the **omasum** is thrown into broad longitudinal folds or leaves reminiscent of the pages in a book (a lay term for the omasum is the 'book').
- The omasal folds, which in life are packed with finely ground ingesta, have been estimated to represent roughly one-third of the total surface area of the forestomachs.

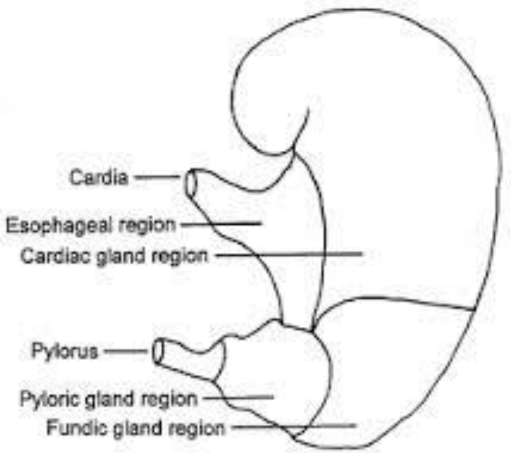


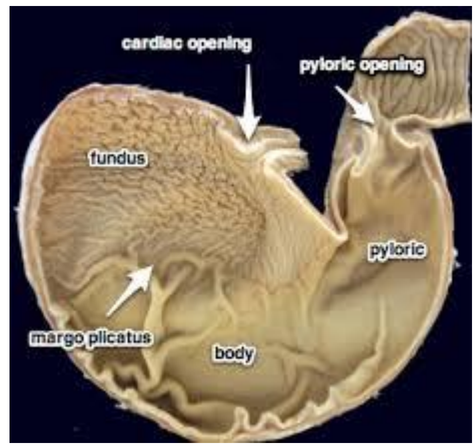
TOPOGRAPHY OF VENTRAL SIDE OF ABDOMEN OF A NON-PREGNANT 5-YEAR-OLD COW



Large Intestine
Small Intestine
Mouth
Esophagus
Rumen
Pelvic bone
Bladder
Reticulum
Abomasum
Omasum

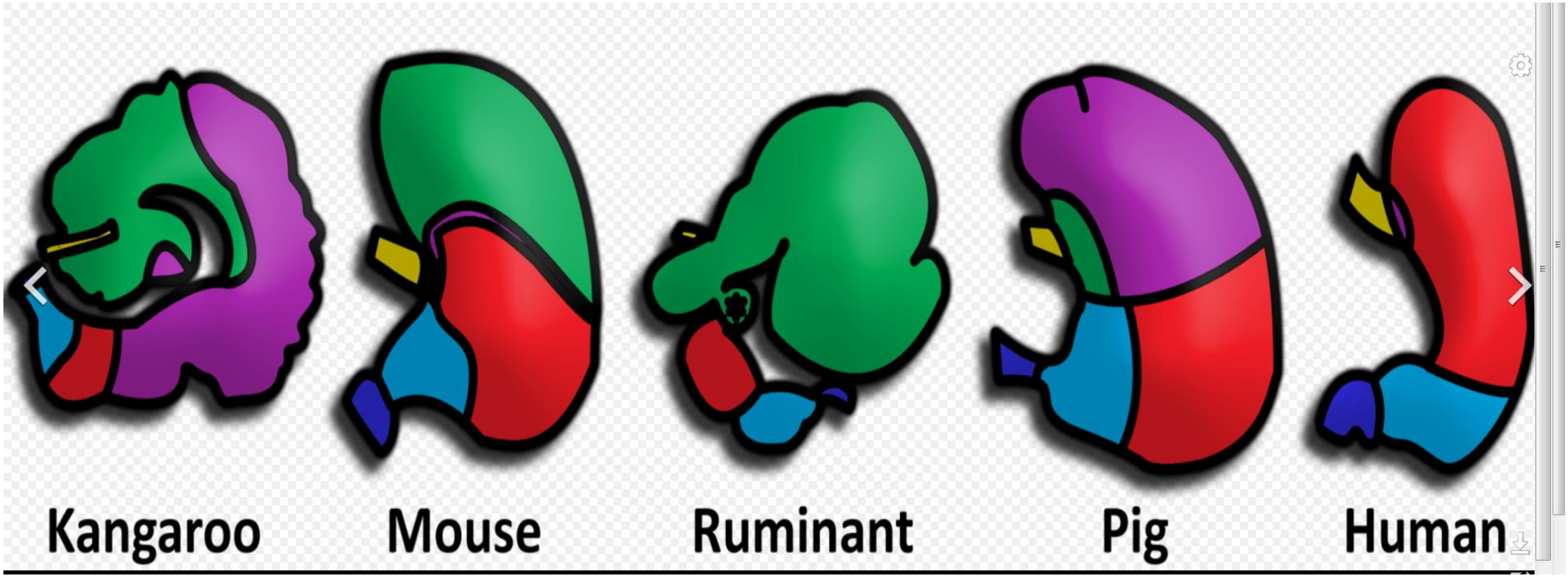
Pig Stomach





The cardia is where the contents of the esophagus empty into the stomach
The ***fundus*** is formed by the upper curvature of the organ.
The ***body*** is the main, central region.
The **Pylorus** is the lower section of the organ that facilitates emptying the contents into the small intestine

Comparison of stomach glandular regions from several mammalian species. Yellow: oesophagus; green: glandular epithelium; purple: cardiac glands; red: gastric glands; blue: pyloric glands; dark blue: duodenum



Name	Secretion	Region of stomach
Mucous neck cells	mucus gel layer	Fundic, cardiac, pyloric
parietal (oxyntic) cells	gastric acid and intrinsic factor	Fundic only
chief (zymogenic) cells	pepsinogen and gastric lipase	Fundic only
enteroendocrine (APUD) cells	hormones gastrin, histamine, endorphins, serotonin, cholecystokinin and somatostatin	Fundic, cardiac, pyloric