

INTRODUCTION AND DIGESTIVE PHYSIOLOGY

ROLE OF PIGS?

“If the domestic pig had its way, it would replace the dog as man's best friend instead of his best source of protein!”

(Anonymous)

1. Pigs . . . Those Wonderful Creatures!

“Dogs look up to you, cats look down on you and pigs think you're their equal!”

(Cited by Hedgepeth, 1978)

“There's lots of psychology in handling pigs, he says. You can force a dog, a chimp or a horse to do something, but a pig, NO! Pigs won't take punishment. Reprimanding will work for a dog, but with a pig, NEVER! If you reprimand a pig he won't like you, won't respond to you and won't even take food from you. You can see temper in pigs. If I scold them, they scold right back!”
[Frank Inn (trained “Arnold Ziffel” for TV show, “Green Acres”). Cited by Hedgepeth, 1978]

“As people we have not used the pig too well. We have maligned, reviled and looked down on him. We have made 'dirty as a pig' a measure of complete uncleanness, even though the pig is by choice most cleanly. We have called him 'hoggish,' though he eats only what is good for him and never too much. Yet, cursed and badly appreciated, he has done all right by himself. He has gone his way, dignified and more nearly self-sufficient than the rest of our domestic animals.

Though submitting to man's authority, he has remained a rebel and independent.”

(Cited by Hedgepeth, 1978)

*“Hogs appear to possess a degree of honest emotional sensibility that clearly sets them apart from their domesticated cohorts of farm and field. **Mules** - Excessively dour and ill-tempered. Few people report seeing a truly happy mule - attitudinal problem generally thought to be the result of their profound and obvious sexual deficiency. **Cows** - A cow clumps along, chews grass, swishes its tail and means well, God knows, but insists on 'mooing' in undifferentiated response to almost anything. 'Moo' being, on top of its other drawbacks, an absurd sound and virtually impossible to take seriously. **Sheep** - Sheep run in flocks and are, therefore, quite nearly helpless without shepherd assigned to the task of 'keeping watch o'er their flocks.' So . . . through it all, it is the hog who remains the most richly dimensioned and enigmatic of creatures. . . perhaps humankind's subconscious fascination with hog is rooted in the sensation that he seems far less like an animal, in the sense of the word, than are the other living things we are accustomed to dealing with in their undisputed role as animals.”*

(Hedgepeth, 1978)

2. “Talk Hog” with a Hogman

In the south, it is “**Hawg**,” like “Dawg.”

In certain Appalachian regions, it is “**Howg**.”

In the middle and northeastern Atlantic states, and among Jewish hogman (of whom there are very few), it is “**Hawug**.”

In New England, it is pronounced “**Hahg**,” and

Midwesterners, who have more hogs about them than any other Americans, thus having some special insight into the subject, tend toward “**Hogg**,” with a very short “o.”

In Ireland and much of Great Britain, hog is pronounced “**Pig!**”

3. Hog Expressions

“**Dirty**” or “**Greedy**” or “**Fat**” as a pig.

“**Piggish**” or “**Hoggish**” or “**Swinish**” - Meaning selfish or carnal.

“**Pigheaded**” - Referring to stubbornness.

“**Making a Pig**” of oneself - Meaning to overeat.

“**Brought up in a Pigsty**” - Means that someone is slovenly.

“**Live High on the Hog**” - Is to splurge in an overindulgent style of life.

“**Hog Heaven**” - Is supreme material bliss.

- *The expression coined primarily as an insult directed toward humans for acting some certain way . . . or toward hogs for the fact that undesirable people are drawn to parody and besmirch their patterns of behavior???*

4. Pork Facts

A. ≈ 800 million to 1 billion pigs produced/yr in the world.

B. ≈ 100-120 million pigs/yr in the U.S.

C. ≈ < ½ million pigs/yr in Alabama in recent years.

D. Consumption of pork (per capita): 1) ≈ 65 lb/yr in the U.S., and 2) ≈ 25 lb/yr in the world.

E. Worldwide meat consumption: 1st, Pork (44%), and 2nd, Beef (31%) [Smith, 1992. Feedstuffs 64(40):6.]

5. Contributions of Swine

A. Swine industry & U.S. economy:

- 1) Inputs for the swine industry in 1985 - 1.13 billion bu of corn (\$2.35 billion) and 6.5 million tons of supplements (\$1.42 billion). (Feedstuffs, 1987)
- 2) In 1992, the swine industry was responsible for 764,000 jobs and \$66.05 billion in the US economic activity. [NPPC, 1993/94. Pork Rep. 12(6)12.]

- B. Convert feeds into products of a “higher” value:
- 1) A 3-ounce serving of lean pork provides (% of RDA) 42% of protein, 35% of thiamin (B₁), 19% of zinc & 10% of iron, and pork is also an excellent source of riboflavin (B₂), B₆, B₁₂ & others.
 - 2) A 3-ounce serving of lean pork contains:
 - a) Only ≈ 197 calories (lower than lamb or beef).
 - b) Only ≈ 77 mg cholesterol (lower than lamb, veal or dark turkey meat).
 - c) Less saturated fat (as little as 1/3) than beef or lamb.
- C. Can utilize waste products - Table garbage, bakery wastes, unmarketable grains, vegetables & fruits . . . , etc.
- D. Can utilize “low-quality” food grains & “unsound and damaged” feeds.
- E. Can utilize forages - Mostly for gestating sows, but growing-finishing pigs can also utilize pasture, forages, ground legume hay/meals, and others.
- F. Stabilizing influence on the market value of grains.
- G. Aid in maintaining soil fertility.
- H. Provide profit potentials.

THE PIG AS A MODEL FOR HUMAN RESEARCH

☞ *Excellent references: 1) Miller & Ullrey, 1987. Annu. Rev. Nutr. 7:361, & 2) Pond, 1991. In: Miller, Ullrey & Lewis (Ed.) Swine Nutrition. p 3. Butterworth-Heinemann, Boston.*

1. The Pig & Humans (Similarities)

- A. Dental characteristics.
- B. Renal morphology and physiology.
- C. Eye structure and visual acuity.
- D. Skin morphology and physiology.
- E. Cardiovascular anatomy and physiology.
- F. Digestive anatomy and physiology.

2. The Pig in Biomedical Research

- A. General areas - Cardiovascular physiology, obesity, stress, dermatology, toxicology, immunology, behavior, renal physiology, experimental surgery, gastroenteritis, Diabetes, drug metabolism, etc.
- B. Byproducts of the pig - Heart valves, skin for burn patients, hormones (insulin, thyroxine, pituitary hormones), blood for transfusion (?), etc.
- C. Nutrition (digestion, metabolism & requirements):

- 1) Baby pigs fed protein and(or) energy deficient diets can be used as a model for human infant conditions of Kwashiorkor and marasmus.
 - 2) Models for infant total parenteral nutrition studies.
 - 3) Effects of dietary lipids on pigs can be applicable to humans - e.g., cholesterol, lipoproteins & others on cardiovascular system.
 - 4) Understandings/knowledge of amino acid metabolism obtained from pigs can be applicable to human nutrition.
 - 5) Iron deficiency anemia in nursing baby pigs can be a model for iron deficiency in human babies.
- . . . , etc.

PIGS, POULTRY, AND HORSES

1. Similarities Between Pigs & Poultry

- A. Are nonruminants, ∴ less “meaningful” symbiotic relationships with microorganisms along the gastrointestinal system vs ruminants.
- B. Need amino acids, not protein *per se*.
- C. Have a limited ability to utilize fibrous components of the diet.
- D. Diets consist predominantly of grains and soybean meal in the modern production system, ∴ more susceptible to mineral and(or) vitamin deficiencies.
- E. Are raised in confinement facilities in the modern production system.
- F. Are relatively fast growing & efficient in conversion of feed to body tissues.

2. Differences

- A. Pigs are delivered in the “litter,” and chicks are hatched from the “egg” - “Chicks” embryonate away from its dam, ∴ eggs must contain all essential nutrients before being laid/incubation!
- B. Pigs have hair, and chicks have feathers - “Chicks” - Feathers make up a relatively larger proportion of body weight, ∴ influencing the requirement for certain amino acids.
- C. Pigs have an immature digestive system at birth, whereas chicks have a full complement of digestive enzymes at hatching - “Chicks” can utilize corn and soybean meal diets efficiently from day one, whereas baby pigs must depend on milk or milk-based diets!
- D. Chicks have higher metabolic rate, respiration rate and heart rate.

☞ May want to read : “Schmidt-Nielsen, K. 1970. Energy metabolism, boy size, and problems of scaling. Fed. Proc. 29:1524-1532.”

- E. Laying hens mobilize large amounts of Ca, and are susceptible to leg problems. (Also true for lactating sows!)
- F. Chicks have a different digestive tract and digestive process:

- 1) No teeth.
- 2) Have a crop and gizzard, and no true stomach for storage or enzyme secretion.
- 3) Have two ceca which contribute little to digestion.
- 4) Have a very fast rate of digesta passage.
- 5) Absorb fatty acids via portal system - Lymphatic system is poorly developed.
- 6) Excrete N as "uric acid" - Influences the requirement for certain amino acids, and dietary metabolizable energy values.

3. How About Horses?

- A. Classified as one of the nonruminant species based on the anatomy of the digestive tract.
- B. But, more specifically, the horse is a hind gut fermenter, thus may possess some advantages of the strict nonruminant and ruminant species - i.e., have some effects on protein/amino acid needs, fiber utilization, and(or) vitamin needs.

DIGESTIVE SYSTEMS - FROM FEED DETECTION TO ESOPHAGUS

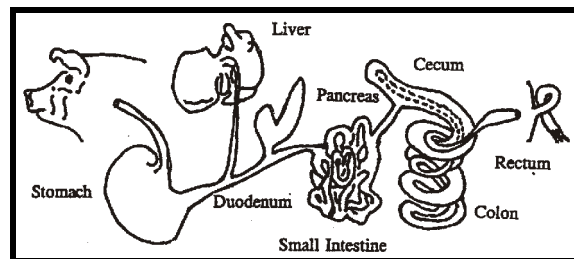
☞ Excellent references on "digestive physiology:" 1) Kidder and Manners, 1978. *Digestion in the Pig*, 2) Davenport, 1982. *Physiology of the Digestive Tract*, and 3) Moran, 1982. *Comparative Nutrition of Fowl and Swine. The gastrointestinal Systems*.

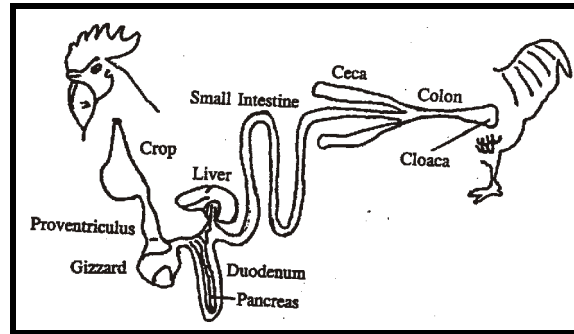
1. The Pig

*"We feed our horses hay and oats, with grass for cows and sheep and goats.
Chickens look for grain to eat, while ducks find worms, and dogs get meat.
Cats have meat and milk and fish. To each, its own peculiar dish.
Some are fussy, others not, but pigs, of course, will eat a lot."
(Kidder & Manners, 1978)*

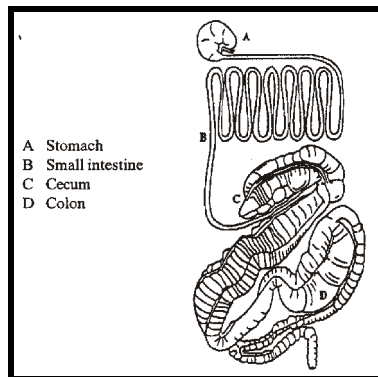
- A. Classified as an "omnivour."
- B. Has a digestive system that is well adapted to a wide variety of foods.

2. Swine & Fowl Gastrointestinal Systems (Adapted & redrawn from Moran, 1982)





3. Horses digestive tract



4. Sight & Smell

- Fowl and swine retinæ have both rod and cone cells, ∴ they can see “color.” (Perception of color is probably poor in pigs compared to birds.)
- Birds have poor sense of smell, ∴ depend mostly on acute eye sight in seeking food, whereas pigs are completely opposite!

A. Poultry:

- 1) Eyes occupy a larger proportion of head in fowl than in pigs, and also domestic fowl's eyes are located laterally on the head (vs frontal in pigs), ∴ a much greater panoramic view or larger retinal image for birds vs pigs.
- 2) Have a greater No. of visual cells communicating to the brain (vs pigs).
- 3) Have a poorly developed sense of smell.

☞ Their sense of smell may be oriented toward other purposes, i.e., other than feed detection and(or) evaluation such as ascertaining “orientation & direction.”

B. Swine:

- 1) Eyes are recessed and shielded, and also their eyes are located more frontally (i.e.,

about 70° visual axis) than other non-carnivorous animals, ∴ a lower visual capacity compared to birds.

- ▶ Probably, the result of an evolutionary protective mechanism arising from extensive burrowing in the search of food?
- 2) Overall, pigs are well equipped with olfactory apparatus, and the sense of smell is used extensively in seeking/evaluating feeds. (Also, important in detection of sex steroids, identification of individuals, etc.)

5. **Mouth**

A. Swine:

- 1) Snout - Designed for rooting & digging for food.
- 2) Teeth:
 - a) Incisors for biting, grazing, etc.
 - b) Canine teeth (long and sharp in the male).
 - c) Molars for chewing - (1) To divide food into fine particles, ∴ increasing the surface area, and (2) to mix with saliva for swallowing.

B. Poultry:

- 1) Comprised largely of “hard” tissues, i.e., very little oral manipulation of food.
- 2) ∴ difficulty in consuming larger or smaller particles: a) Too large - Cannot divide, and b) Too fine - ↓ efficiency, i.e., need additional work, which ↑ the energy expenditure.

6. **Taste**

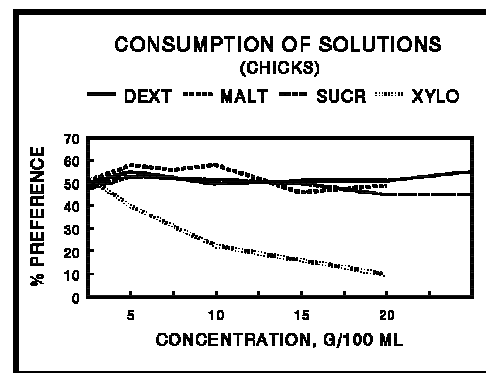
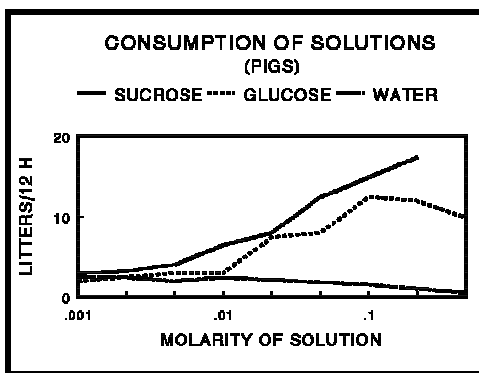
A. Total No. of taste buds in the mouth: [Kare & Ficken, 1963. In: Y. Zotterman (Ed.) Olfaction and Taste]

Animal	Number
Chicken	24
Pigeon	37
Japanese quail	62
Duck	200
Parrot	350
Kitten	473
Bat	800
Pig	15,000
Rabbit	17,000
Calf	25,000
Human	9,000

- 1) Taste buds - A group of cells that are approximately 20 x 90 μ in size.
- 2) Taste buds are located throughout the oral cavity, particularly on tongue in pigs, whereas they are restricted to or located on the back of the mouth in birds.

☞ Taste apparatus is present in fowl, but not extensive as in swine!

- B. Consumption of various solutions by pigs (Adapted & redrawn from Kennedy & Baldwin, 1972. Anim. Behav. 20:706 - See Figure on the left), and Consumption of various solutions by chicks (Adapted & redrawn from Kare & Medway, 1959. Poult. Sci. 38:1119 - See figure on the right):



C. The Bottom Line:

- 1) Taste preferences exist in swine! But addition of sugar/flavors in the diet has been resulted in very inconsistent responses or minimal effects on performance.
- 2) A sense of taste also exists in poultry:
 - (1) But, may be associated more with “aversion” rather than “preference.”
 - (2) Ingredients with different taste had minimal beneficial or adverse effects on poultry.
 - ▶ May respond to flavor changes more when water is a medium rather than feed because of the absence of a fluid saliva & mastication in birds.

7. Salivary Glands

A. Swine:

- 1) Saliva contains water, mucus & ptyalin (or salivary α -amylase), and moistens feed, lubricates esophagus and initiates starch digestion.
- 2) Types:

- a) Serous - Contains water, electrolytes & α -amylase.
 - b) Mucus - Contains mucoproteins.
 - c) Mixed
- 3) Glands (three pairs are responsible for most secretions):
- a) Parotid - Largest, triangular in shape & located at the apex ventral to the ear, and secrete fluid devoid of mucin.
 - b) Submaxillary or submandible - Found ventral to the parotid & just behind mandibles, and secrete mucin-containing saliva (mixed).
 - c) Sublingual - Closely associated with the tongue & found below the floor of mouth, and secrete mucin-containing saliva (mucous).
- 4) Type of diets & saliva flow rate: (Cromwell. Pers. Comm.)

Feed	ml/1st 5 min
Corn	55
Potatoes	27
Milk	0

- (3) Secretion rate is affected by the DM content of diets.
- (4) \approx 1-2 liters/d on a conventional dry diet.
- (5) Saliva flow is stimulated mostly by the presence of food in the mouth.

B. Poultry:

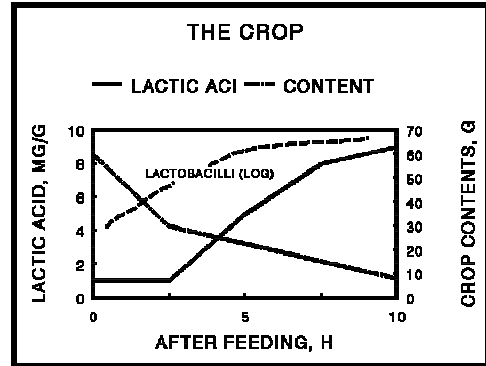
- 1) Minimum in the quantity.
- 2) Glands composed entirely of mucus cells, \therefore secrete only thick mucus type saliva.
- 3) Probably, saliva is nothing more than just lubricating “food bolus” in poultry.

7. Esophagus

- A. Swine - “Peristaltic action” (wave of contractions) moves food (as a form of "bolus") to the stomach.
- B. Poultry - It is relatively similar to that of the pig, but birds have “crop,” and their esophagus is longer in terms of body dimension:
 - 1) The crop in general:
 - a) Is an esophageal “outpocketing.”
 - b) Mucus glands in the upper esophagus lubricate & move “bolus” to the crop.
 - c) The crop is filled & emptied by peristaltic movements.
 - d) A main function of the crop? - Probably serving as a food storage site.

2) But, there are some microbial & digestive activities in the crop:

- a) Hydrolysis of starch.
 - b) Lactobacilli & lactic acid production:
 [Adapted & redrawn from Jayne-Williams and Fuller, 1971. In: D.J. Bell & B.M. Freeman (Ed.) Physiology & Biochemistry of the Domestic Fowl]
- Organic acids (. . . mostly lactic & acetic acids) account for ≤ 3% of maintenance needs!



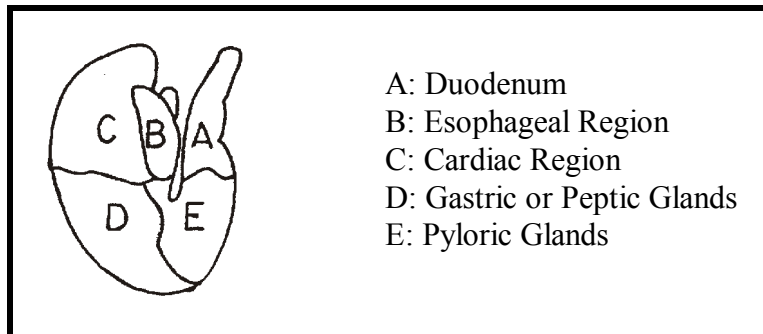
3) The importance of crop?

- a) Maintaining the microbial balance (e.g., inhibition of *E. coli*).
- b) But, not essential for “well-being” or maximal performance of the bird unless feed is restricted severely, i.e., the crop provides more flexibility to the animal!

THE STOMACH

1. **Swine** - “Stomach” is serving as a reservoir for food, but some digestion takes place:

A. The pig’s stomach: [Adapted & redrawn from Pekas, 1991. In: Miller, Ullrey & Lewis (Ed.) Swine Nutrition]



B. Esophageal:

- 1) An extension of the esophagus into the stomach.
- 2) Glandless area, ∴ no secretion.
- 3) Subject to "ulceration."

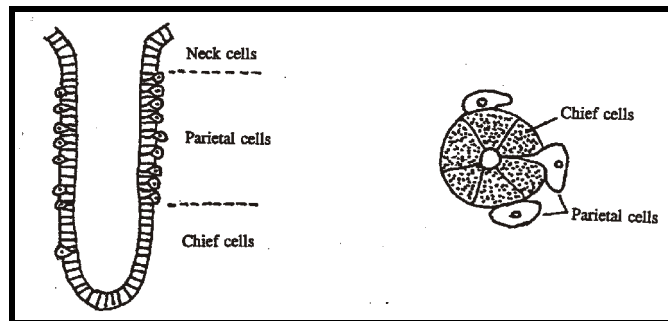
- Processing (e.g., fine grinding, pelleting, etc.) or diets that tends to make stomach contents more fluid can cause “ulcer” in pigs!

C. Cardiac:

- 1) Located adjacent to the esophageal area, and occupies about $\frac{1}{3}$ to $\frac{1}{2}$ of the stomach area in the pig.
- 2) Secretes mucus, which can protect stomach linings from HCl.

D. Fundic or gastric:

- 1) The major secretory portion of the stomach.
- 2) Three types of cells:



- a) Neck cells are responsible for secretion of mucus.
- b) Oxyntic (parietal) cells are responsible for secretion of HCl & exchange of Na^+ with H^+ . (“HCl” denatures protein, activates pepsin (from pepsinogen), provides optimal pH for pepsin, etc.)
- c) Chief cells are responsible for secretion of enzymes, electrolytes and water:
 - (1) Pepsinogen (pepsin).
 - (2) Electrolytes such as Na, K & Cl.
 - (3) Rennin in young pigs - Acts on casein to form a “curd.”

E. Pyloric:

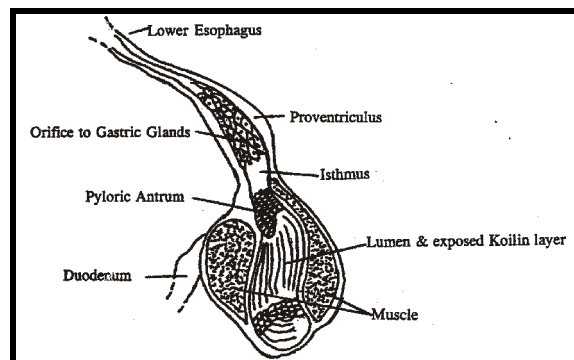
- 1) The last region before entry into the SI.
- 2) Responsible for secretion of a hormone, gastrin:
 - ▶ Gastrin is responsible for secretion of acid, water, electrolytes, enzymes, etc.

F. Control of gastric secretion:

- 1) Cephalic phase:
 - a) Food perception by senses can lead to “vagal stimulation” of glands.
 - b) Plays significant part in the initiation of eating after fasting.
 - ☞ Make small contributions in swine & poultry because their gastric lumens are seldom empty between meals!
 - 2) Gastric phase:
 - a) A combination of distension and chemical sensors.
 - b) Distension of the stomach can activate neural receptors.
 - c) Chemical stimulations involve pH and(or) digesta sensitive cells.
 - 3) Intestinal phase:
 - a) The response to digesta in the duodenum, which is mediated by hormonal and neural mechanisms.
 - b) Hormones in this phase include gastric inhibitory polypeptides (GIP), cholecystokinin, etc.
 - c) Neural mechanisms would be expected, but have not been clearly demonstrated.
- ☞ “Gastrin” is probably the focal point of controlling gastric secretions!

2. Poultry

- A. Use the crop for storage, and proventriculus and gizzard for gastric digestion:
 - 1) Proventriculus provides HCl and pepsinogen.
 - 2) Gizzard is a site for grinding & gastric digestion.
- B. Proventriculus-gizzard complex: [Adapted & redrawn from Hill, 1971. In: D.J. Bell & B.M. Freeman (Ed.) Physiology & Biochemistry of the Domestic Fowl.]



1) Proventriculus:

- a) An ovoid structure found between the lower esophagus and gizzard.
- b) Two types of cells for secretion:
 - (1) “Oxynticopeptic” cells are structurally intermediate between chief and oxyntic cells of mammals, and are responsible for secretion of pepsinogen and HCl.
 - (2) The second type is similar to the neck cells of mammals, and those cells are responsible for secretion of mucus.
- c) Little is known about the control of gastric secretion, but mechanisms similar to those of mammals may exist.

2) Gizzard (ventriculus or “muscular stomach”):

- a) It combines the activity of grinding and proteolysis.
 - b) Has a massive musculature and extremely durable luminal lining.
 - c) The luminal lining is synthesized continually as it’s worn away by constant abrasions.
- ☞ However, the response to the addition of “grits” in diets, thus in the gizzard, has been very inconsistent in terms of performance!

3. Horses

A. Compared to others, have a small stomach - ≈ 10% of volume: [Capacities (L) of Digestive Tract (Argenzio, 1993. In: Swenson & Reece (Ed.) Dukes’ Physiology of Domestic Animals. 11th Ed. Comstock Publishing Assoc., Ithaca]

Item	Horse	Pig	Dog
Stomach	17.96 (8.5%)	8.00 (29.2%)	4.33 (62.3%)
Small Intestine	63.82	9.20	1.62
Cecum	33.54	1.55	0.09
L. colon	81.28	8.70 (Colon + rectum)	0.91 (Colon + rectum)
S. colon & Rectum	14.77		
Total	211.34	27.45	6.95

B. A flow rate - Relatively fast.

- 1) A large meal passes more quickly vs feed eaten continuously in small amounts.
 - 2) Passing of majority of ingesta to the small intestine within 12 h following a meal?
- C. When the stomach remains empty, the excess gas produced can cause rupture of the stomach. Thus, “continuous consumption” would be optimum?

THE INTESTINAL SYSTEM

☞ Regardless of the species, most of digestion and absorption of nutrients take place in the small intestine!

1. Swine

☞ *Articles by Pekas [1991; In: Miller, Ullrey & Lewis (Ed.) Swine Nutrition] and Yen [2001; In: Lewis & Southern (Ed.) Swine Nutrition. 2nd Ed.] contain excellent diagrams of the swine intestinal system.*

A. Swine intestinal system in general:

- 1) The SI in a fully grown pig:
 - a) \approx 18 m long, and the body length to SI length ratio is \approx 1:14. (Ratios for other species - horse = 1:12, cattle = 1:20, sheep/goat = 1:27, dog = 1:6 & cat = 1:4.)
 - b) \approx 90% as jejunum & remaining 10% divided equally between duodenum & ileum.
- 2) The LI (a fully grown pig) - \approx 5 m long & first 7-8% being cecum.

B. Duodenum:

- 1) Primarily a mixing site for digesta:
 - a) Responsible for secretion of viscous & alkaline substances, which protect the intestinal wall from "acidic" gastric contents.
 - b) “Bile” (stored in the gall bladder) from liver contains 97% water, 0.7% salts, 0.2% pigments, 0.06% cholesterol & others.
 - c) Pancreatic secretions:
 - (1) Alkaline substances are rich in bicarbonate, and buffer "acidic" contents from the stomach.
 - (2) Digestive enzymes include lipase, amylase, trypsin, chymotrypsin, carboxypeptidases, etc.
 - (3) Controlled by two hormones:

- (a) "Secretin" stimulates bicarbonate & water flow.
- (b) "CCK-PZ" stimulates enzyme flow.

2) The volume of secretions in a 40-kg pig:

- a) Bile - 2 liters/day.
- b) Pancreatic fluids - 5 liters/day.
- c) Total fluids - 10 liters/day.
- ☞ The flow from the stomach is \approx 3 liters/day, plus passage of \approx 2 kg of feed & 5 liters of water/day!

C. Jejunum & ileum:

1) "Villi" cover the SI, which increase the surface area:

- a) Longest in the jejunum, and the length decreases progressively.
- b) Very active area with rapid turnover of cells - \approx 20-30 million cells sloughed off/min.

2) Brush boarder enzymes are located at the brush boarder of the intestinal villi:

- a) Enzymes include aminopeptidase, dipeptidase, sucrase, maltase, lactase, phosphatase, polynucleotidase, lecithinase, etc.
- b) Enzymes are integral parts of the membrane at the brush boarder, i.e., not secreted, but "shed" into the lumen.
- ☞ The jejunum digests & absorbs the majority of nutrients!

D. Cecum and colon:

1) The site to retrieve nutrients remained in digesta before excretion - primary nutrients recovered are water & electrolytes.

2) Fairly high in the microbial population:

a) "VFA" produced by microbes:

- (1) Can be absorbed, and may be an important source of energy.
- (2) May contribute as much as 30% of maintenance energy for older animals vs only 2-3% for young animals (obviously, there are differences among species!).

b) Synthesis of vitamin K & B-vitamins by microbes:

- (1) Absorption - ???

(2) Obtaining vitamins via coprophagy may be important/significant in some situations.

c) Synthesis of amino acids:

(1) When lysine is infused into the cecum, "N" appears as urea in the urine or excreted in the feces, indicating that AA synthesized are used by other microbes or metabolized by the intestinal wall.

(2) ∴ may have no or little value to the pig.

E. Apparent digestion coefficients: (Keys & Debarthe, 1974. J. Anim. Sci. 39:57)

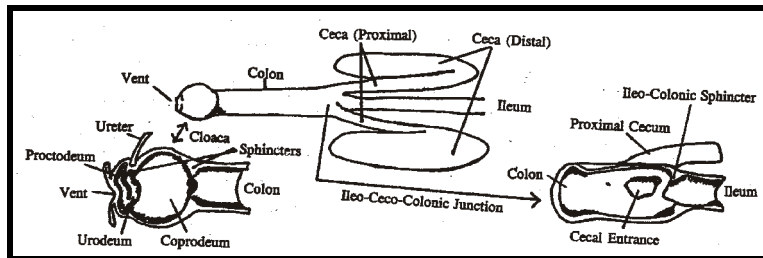
Item	Site	Wheat	Corn	Barley
DM	Duodenum	3.9	4.1	2.5
	Ileum	68.5	66.6	63.6
	Rectum	81.7	80.7	81.0
Energy	Duodenum	4.5	-7.3	-5.9
	Ileum	69.6	65.8	62.2
	Rectum	82.9	78.4	80.2
Protein	Duodenum	42.3	20.1	25.9
	Ileum	74.5	74.6	66.7
	Rectum	84.1	81.7	78.7

2. Poultry

A. Small intestine:

- 1) ≈ 125 cm long & occupies ≈ 50% of the total GI tract in adult chickens.
- 2) Relatively short, but ↑ absorptive effectiveness by using “back & forth” peristalsis.
- 3) In general, similar to swine in anatomy and functions.

B. Large intestine: (Adapted & redrawn from Moran, 1982)



- 1) Have a short colon and two long ceca (vs a short cecum & long colon in swine).
- 2) Ceca:

- a) Only fluids, solutes and fine particulate matters may enter the ceca.
 - b) Microbial activities:
 - (1) A main site for VFA production, but make a small contribution to the overall needs.
 - (2) Vitamins can be synthesized, but their availabilities are low.
 - 3) Colon - Probably acts more to convey ileal and cecal digesta rather than active fermentation & absorption.
- ☞ Both the ceca & colon are capable of absorbing water, electrolytes, glucose & amino acids.

C. Cloaca:

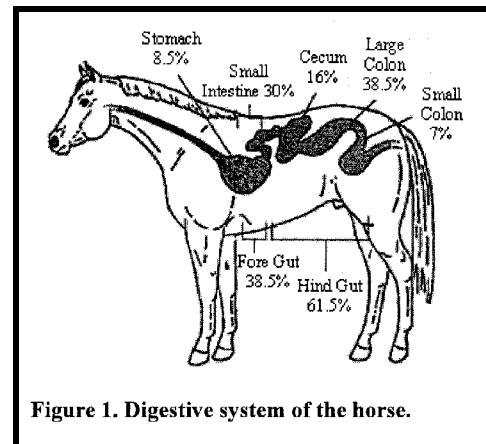
- 1) It combines functions of both rectum & bladder into one.
- 2) Mechanisms are present to conserve water & NaCl (processes require energy) if the situation demands.

3. Horses

- Diagram: <http://www.ianr.unl.edu/pubs/horse/g1350.htm>.

A. Small Intestine:

- 1) About 30% of the volume of the total digestive tract.
- 2) The main site of both digestion & absorption.
- 3) Flow rate - Affected by the size of meal (↑ with larger meals), physical form (e.g., ↑ with pelleted diets & liquids), etc.
- 4) Within 2-4 h, undigested & unabsorbed ingesta to the cecum & colon.
 - ☞ Easy to overwhelm the digestive capacity of the stomach and small intestine because of limited “capacity/volume.”
- 5) The horse's digestive system is designed for carbohydrates & proteins in grains to be digested in the upper gut:
 - ☞ Important to feed relatively small amounts, 2-4 times each day for safer, more efficient digestion.



B. Cecum and colon:

- 1) Together, about 50% of the volume of the total digestive tract.
- 2) Microbial digestion.
- 3) With large amounts of concentrates, rapid fermentation & production of excessive gas or lactic acid, causing colic or laminitis.
- 4) Flow rate - Relatively slow . . . may be several days following eating?
- 5) The diameter of different segments of the large colon varies & arrangement includes several flexures where the colon turns back onto itself, susceptible to digestive upsets when nutrient flow is abnormal. (Fewer problems with hay & pasture though!)

LIVER AND PANCREAS

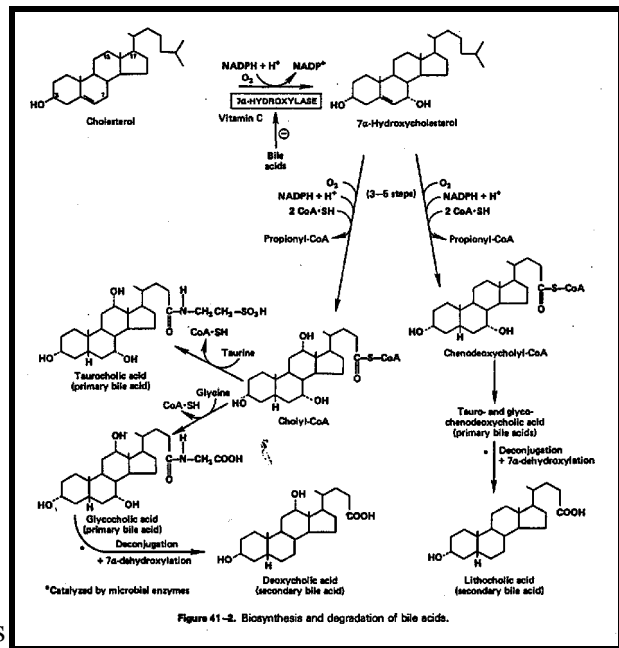
1. Liver

- A. About 3 and 1.75% of body weight for the fowl and swine, respectively.
- B. Vital to digestion & assimilation of absorbed nutrients:

- 1) Bile for emulsification of dietary fat - See “Biosynthesis & degradation of bile acids” by Martin et al. (1983).
- 2) Makes metabolic modifications - Majority absorbed nutrients pass through the liver.
- 3) Mostly associated with the maintenance metabolism in adult animals (i.e., in those not involved in reproduction!).

- C. Lobes - Two in the fowl and several lobes in the swine, but fundamentally similar in shape, location of gall bladder and major vessels.
- D. Vascularization:

- 1) Pigs receive blood from the portal vein (nutrients) & hepatic artery (O₂), and blood exits through the hepatic vein and lymphatic system.
- 2) Similar in the fowl, but a contribution of lymphatic system is small (vs swine) simply because it is poorly developed in birds.



E. Bile & digestion/absorption of lipids:

- 1) Formed by the hepatocyte - All bile acids are steroidal compounds synthesized from cholesterol in the liver:
 - a) Composition - Water, bile acids, mucin, pigments, cholesterol, esterified & free fatty acids and inorganic salts.
 - b) Cholic & chenodeoxycholic acids are 1° acids, but pigs produce little cholic & hyocholic acid takes place as the 1° trihydroxy unit.
 - c) To reduce their toxicity, all bile acids are conjugated with taurine in fowl & either taurine or glycine in pigs.
 - d) Secondary bile acids - Arise from microbial fermentation when 1° acids are within the intestine . . . after absorption, can be reused by the live for bile synthesis.
 - e) Bile pigments - Metabolic end products of heme catabolism & give the bile its characteristic color . . . biliverdin, bilirubin . . .
- 2). Secreted from the live directly into the duodenum or via gallbladder (stores bile, which is little more concentrated vs hepatic bile).
- 3) Control of bile movement - “More” via intramural plexus coordination (e.g., gastric digesta/lipids & neural receptors) than the hormone, cholecystokinin (CCK)?
- 4) Enterohepatic circulation - $\approx 99\%$ of the primary and secondary bile acids are absorbed in the ileum and return to the liver via hepatic portal vein.
- 5) Daily bile acid use by the animal - Far exceeds its capacity for synthesis:
 - a) An enterohepatic recirculation to cope with the demand.
 - b) Control of the total pool of bile to meet the needs.
- 5) Functions of bile:
 - a) Emulsification - The bile salts have considerable ability to lower surface tension, \therefore capable of emulsifying fats (micelle formation).
 - b) Neutralization of acid - The bile is a reservoir of alkali.
 - c) Excretion of cholesterol, and also many drugs, toxins, bile pigments, inorganic substances (e.g., Cu, Zn & Hg), etc.

2. Pancreas**A. Two major functions:**

- 1) Supplying enzymes to the SI for starch, protein & fat digestion. (Also, cannot ignore the secretion of water, bicarbonate & others into the duodenum area!)

- 2) Supplying hormones to manipulate nutrient metabolism on a moment-to-moment basis.

B. Gross appearance & anatomy:

1) Swine:

- a) Pinkish-red in color.
- b) Difficult to discern because of connective tissues, adipose tissues, etc.
- c) Ductules permeate the gland & give rises to one duct, which supply zymogens to the duodenum area.

2) Fowl:

- a) Grey-white in color.
- b) Visually apparent.
- c) Have three separate lobes with ductules.
- d) All ducts meet on a common papilla with two bile ducts at the duodenal-jejunal junction.

C. Exocrine tissues & endocrine islets:

1) Acinar tissues dominate pancreatic tissues:

- a) Acinar cells are responsible for secretion of enzymes or zymogens.
- b) Centroacinar & duct cells are responsible for secretion of water, electrolytes, etc.

2) Islets of Langerhans - Distributed throughout the pancreas:

- a) A-cells - Glucagon.
 - b) B-cells - Insulin.
 - c) D-cells - Somatostatin.
 - d) F-cells - Pancreatic polypeptide.
- ▶ A-, B- & D-cells are found in every islets in pigs, whereas A-/D- or B-/D-cell composite in birds.

D. Islet hormones:

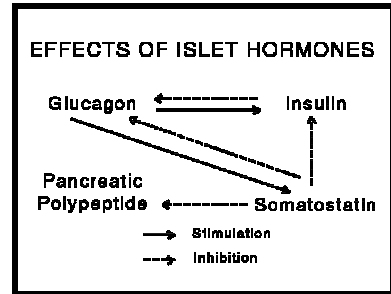
- ▶ The islets may function as secretory units in the regulation of nutrient homeostasis.

1) Effects of islet hormones: (Adapted & redrawn from Ganong, 1983)

2) Somatostatin:

a) Responsible for coordinating “GI tract activities” & regulate the rate of energy (& other nutrients) entry into the animal - responsible for a short term regulation?

b) But, also seems to be involved in a long term homeostasis through instructions from the brain.



3) Insulin - Has glycogenic, antigluconeogenic, antilipolytic, and antiketotic activities. i.e., insulin is a hormone of “energy storage!”

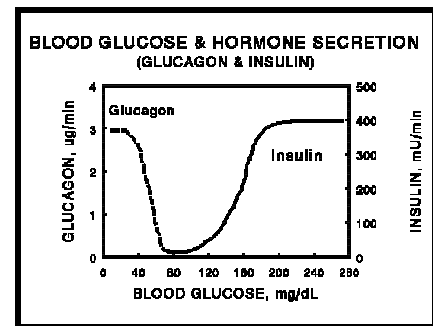
4) Glucagon - Has glycogenolytic, gluconeogenic, lipolytic, and ketogenic activities, i.e., glucagon is a hormone of "energy release!"

5) Control of insulin & glucagon secretions:

a) Many factors affect insulin & glucagon secretions, but the principal factor seems to be plasma glucose.

b) Blood glucose and insulin/glucagon secretions - Adapted & redrawn from Ganong (1983).

c) Insulin-glucagon molar ratios (I/G): (Ganong, 1983)



Condition	Hepatic glucose storage (S) or production (P) ^a	I/G
Glucose availability:		
Large CH ₂ O meal	4+ (S)	70
IV glucose	2+ (S)	25
Small meal	1+ (S)	7
Glucose need:		
Overnight fast	1+ (P)	2.3
Low-CH ₂ O diet	2+ (P)	1.8
Starvation	4+ (P)	.4

^a1+ to 4+ indicate relative magnitude.

(1) Need energy - Lower I/G ratios & favor glycogen breakdown & gluconeogenesis.

(2) Energy need is low - Higher I/G ratios & favor deposition of glycogen, protein & fat.

6) Insulin & glucagon for swine & fowl - Both species have a comparable set of enzymes:

- a) Insulin:
 - (1) Swine - Insulin removes circulating glucose rapidly for hepatic & adipose tissue fatty acid synthesis, i.e., stimulation of pyruvate dehydrogenase & acetyl CoA carboxylase.
 - (2) Fowl - Not responsive to hypoglycemic action of insulin. (Fatty acid synthesis is largely restricted in the liver!)
 - b) Glucagon:
 - (1) Swine - Glucagon affects lipolysis of hepatic stores, but has minimal effect on adipocytes.
 - (2) Fowl - Glucagon can elicit strong lipolytic response.
- ☞ These differences can lead to “obesity” in pigs, and “rapid” release of fatty acids in birds (possibly to cope with daily stress of life?)!
- 7) Pancreatic polypeptide:
 - a) Function or significance has not been completely elucidated.
 - b) Isolated first in chickens:
 - (1) It decreased hepatic glycogen without changing plasma glucose.
 - (2) Also decreased plasma glycerol & free fatty acids.
 - c) Inhibits pancreatic secretions & relaxes gallbladder.

GASTROINTESTINAL HORMONES

- ☞ Secretion and motility in the GI tract are regulated by a combination of nervous & hormonal stimuli.

1. Polypeptide Hormones

- A. Produced by mucosa of various parts of the tract.
- B. Either act locally or released into the circulation.
- C. Many are structurally similar, and exhibit “overlapping” activities.

Gastrointestinal polypeptide hormones: (Martin et al., 1983)

Established hormones:

Gastrin	17
AA residues	

MW	2100
Homologue	CCK-PZ
Location	G cells of antrum & duodenum, brain
Stimulus	Gastric distention & protein in the stomach
Actions	Stimulates acid & pepsin secretion, gastric mucosal growth & possibly lower esophageal sphincter
Cholecystokinin (Pancreozymin) or CCK-PZ	
AA residues	33
MW	3883
Homologue	Gastrin
Location	Mucosa of entire small intestine, brain, islets, etc
Stimulus	Fat, protein & their digestion products
Actions	Stimulates gallbladder contraction, pancreatic enzyme secretion, pancreatic growth, and inhibits gastric emptying
Secretin	
AA residues	27
MW	3056
Homologue	Glucagon
Location	Mucosa of duodenum & jejunum
Stimulus	Low pH in the duodenum (threshold pH, 4.5)
Actions	Stimulates pancreatic & biliary HCO ₃ ⁻ secretion, and augments action of CCK-PZ on pancreatic enzyme secretion

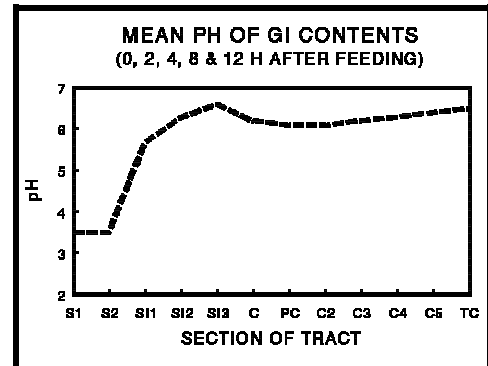
Other hormones:

Gastric inhibitory polypeptide (GIP)	
AA residues	43
MW	5105
Homologue	Secretin, glucagon
Location	Mucosa of duodenum & jejunum, brain
Stimulus	Glucose or fat in the duodenum
Actions	Stimulates release of insulin from pancreas, inhibits gastric H ⁺ secretion & gastric motility, and antilipolytic
Vasoactive intestinal polypeptide (VIP)	
AA residues	28
MW	3100
Homologue	Secretin
Location	Mucosa of entire small intestine
Stimulus	?
Actions	Inhibits gastric H ⁺ and pepsin secretion, stimulates pancreatic HCO ₃ ⁻ secretion & secretion from intestinal mucosa, and inhibits gastric & gallbladder motility
Motilin	
AA residues	22
MW	2700
Homologue	?
Location	Mucosa of duodenum & jejunum
Stimulus	Alkaline pH (8.2)
Actions	Stimulates gastric motility
Enterogastrone	
AA residues	?
MW	?
Homologue	?
Location	Mucosa of small intestine
Stimulus	Fat in the intestine
Actions	Inhibits gastric H ⁺ secretion
Entero-oxyntin	
AA residues	?
MW	?
Homologue	?
Location	Mucosa of small intestine
Stimulus	Protein in the intestine
Actions	Stimulates gastric H ⁺ secretion

Enteroglucagon	
AA residues	?
MW	3500-7000
Homologue	Glucagon
Location	Mucosa of small intestine
Stimulus	Glucose or fat in the intestine
Actions	Glycogenolysis
Chymodenin	
AA residues	43
MW	4900
Homologue	?
Location	Mucosa of small intestine
Stimulus	Fat in the intestine
Actions	Specific stimulation of chymotrypsin secretion by the pancreas
Bulbogastrone	
AA residues	?
MW	?
Homologue	?
Location	Duodenal bulb
Stimulus	Acid in the duodenal bulb
Actions	Inhibits gastric H ⁺ secretion

THE PH AND DIGESTIVE PROCESS

☞ Digestive secretions & type of reactions change as ingesta or digesta moving through the GI tracts in the digestion process.



1. **Mean pH of Gastrointestinal Contents** - Adapted & redrawn from Clemens et al., 1975; J. Nutr. 105:759.)

2. **Significance of pH in the GI Tract**

- A. Low pH in the stomach prevents multiplication of ingested bacteria (except lactobacilli).
- B. Digestive enzymes have a fairly narrow range of optimum pH, ∴ decrease the rate of hydrolysis or activity at either side of the peak.

3. **Summary of the Digestive Process:** (Martin et al., 1983)

Enzyme	Activation & optimum pH	Substrate	End products or action
Salivary gland of mouth - Secrete saliva in reflex response to presence of food in mouth.			
Salivary amylase	Cl ion needed; pH 6.6-6.8	Starch; Glycogen	Maltose + 1:6 Glucosides + Maltotriose

Stomach glands - Chief cells & parietal cells secrete gastric juice in response to reflex stimulation & chemical action of gastrin.

Pepsin A (fundas) & B (pylorus)	Pepsinogen conv. to active pepsin by HCl; pH 1-2	Protein	Proteoses; Peptones
Rennin	Ca needed for activity; pH 4	Casein of milk	Coagulates milk

Pancreas - Presence of "acid-chyme" from the stomach activates duodenum to produce secretin, which stimulates flow of pancreatic juice & CCK-PZ, which stimulates production of enzymes.

Trypsin	Trypsinogen conv. to active trypsin by enterokinase at pH 5.2-6; auto- catalytic at pH 7.9	Protein; Proteoses; Peptones	Polypeptides; Dipeptides
Chymotrypsin	Chymotrypsinogen conv. to active form by trypsin; pH 8	Protein; Proteoses; Peptones	Same as trypsin; more coagulating power for milk
Carboxypeptidase	Procarboxypeptidase to active form by trypsin	Polypeptides at the free carboxyl end	Lower peptides; Free amino acids
Pancreaticamylase	pH 7.1	Starch; Glycogen	Maltose + 1:6 glucosides + Maltotriose
Lipase	Activated by salts, phospholipids, colipase; pH 8.0	1° triacyl- glycerols	FA, Mono- & Diacylglycerols, Glycerol
Ribonuclease		Ribonucleic acid	Nucleotides
Deoxyribonuclease		Deoxyribonu- cleic acids	Nucleotides
Cholesteryl ester hydrolase	Activated by bile salts	Cholesterol esters	Free cholesterol + FA
Phospho lipase A ₂		Phospholipids	FA, lysophospholipids

Liver & gallbladder - CCK, and also possibly gastrin & secretin, stimulates the gallbladder & secretion of bile by the liver.

(Bile salts & alkali)		Fats - also neutralize acid chyme	FA, Bile salt conjugates & Emulsified micelles
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Small intestine - Secretions of Brunner's glands of the duodenum and glands of Lieberkuhn.

Aminopeptidase		Polypeptides at the free amino end	Lower peptides; Free amino acids
Dipeptidase		Dipeptides	Amino acids
Sucrase	pH 5.0-7.0	Sucrose	Fructose; Glucose
Maltase	pH 5.8-6.2	Maltose	Glucose
Lactase	pH 5.4-6.0	Lactose	Glucose; Galactose
Trehalase		Trehalose	Glucose
Phosphatase	pH 8.6	Organic phosphates	Free Phosphate
Isomaltase		1:6 glucosides	Glucose

Polynucleotidase

Nucleic acid

Nucleotides

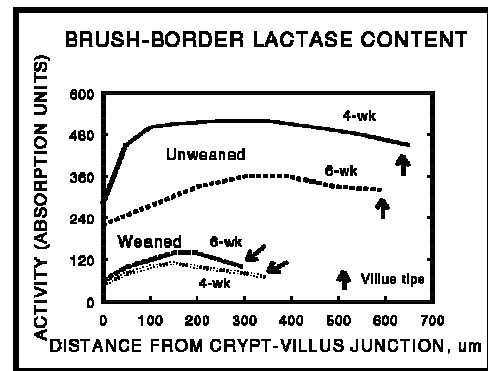
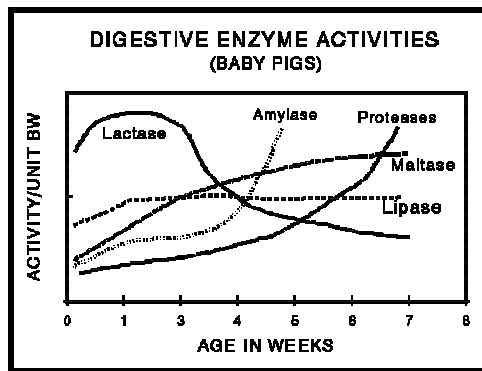
Nucleosidases

Purine or pyrimidine nucleosides

Purine or Pyrimidine bases; Pentose phosphate

BABY PIGS AND DIGESTIVE ENZYMES

1. **Digestive Enzyme Activities** [Adapted & redrawn from PIC Publ. 11(1) - Left]
2. **The Brush-Border Lactase Content in Weaned & Unweaned Piglets** (Adapted & redrawn from Miller et al., 1986. J. Agric. Sci. Cambridge 107:579 - Right)



3. **Age and Digestive Specimen on Protease & Amylase Activities** (Shields et al., 1980. J. Anim. Sci. 50:257)

	Age, wk:	0	2	4	6	8	10
Amylase activity^a							
Total		15	52	98	208	540	1222
Pancreas		5	10	48	164	317	939
Intestinal contents		1	20	21	15	158	207
Intestinal mucosa		9	22	29	29	65	76
Protease activity^b							
Total		6	12	49	84	166	338
Pancreas		5	9	38	57	77	169
Intestinal contents		1	3	11	27	89	169

^aGrams of starch hydrolyzed per minute.
^bMilligram tyrosine equivalents produced per minute.

4. **The Bottom Line?** - *“Pigs have an immature digestive system at birth!”*
 - A. Enzyme profile - Geared toward digesting milk sugar & fat during the first 4 to 5 weeks.
 - B. Enzymes necessary for starch & plant protein digestion are increasing, but still not adequate.
 - C. Thus, to alleviate potential problems, complex diets must be fed to young pigs!

- ☞ Complex diets - Diets containing many special ingredients that are highly palatable & digestible such as milk products (dried skim milk, dried whey), fish products, lipids, sugar, rolled oat groat, etc.

D. Poultry:

- 1) Birds have a full complement of digestive enzymes from day one!
- 2) Thus, can utilize a simple, corn-soybean meal-based diet from day one!

FOOD FOR THOUGHT!

1. Superalimentation?

Effects of superalimentation on performance of pigs^a: (Pekas, 1985. Growth 49:19)

	Control	Super Alimentation	Response (% of C)	<i>P</i>
Body weight, kg				
Day 1	48.3	45.2	-	NS
Day 8	56.4	56.1	-	NS
Day 31	77.3	85.5	+ 10.5	.05
23-d period				
DM, kg	70.9	93.1	+ 31.3	.025
Gain, kg	21.0	29.3	+ 40.0	.005
Gain:feed	.30	.32	+ 7.3	NS

^aSuperalimentation - Started on day 8 at 120% of control intake.