Anatomy and Physiology of the Rabbit and Rodent Gastrointestinal System

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Abstract: Rabbits, guinea pigs, and chinchillas are all classified as hindgut fermenters, depending on primarily cecal microflora for nutrient composition. The rabbit has some unique anatomical features including the sacculus rotundus and the vermiform appendix. Gastrointestinal disorders in these animals can be a challenge to clinicians as not only the motility of the hindgut must be maintained, but the microflora as well. Dysbiosis, or changes in the microflora can release toxins and further alter the pH, microflora and motility. The clinician must also be aware of gastrointestinal pain and hydration status accompanying most gastrointestinal disease.

The Rabbit Gastrointestinal System

Although dental health and thorough examination of the teeth should always be included in the physical examination of a rabbit presented with suspected digestive system disease, this discussion will concentrate on the gastrointestinal system. Nutrition plays an important role in the functioning of the rabbit digestive system and will be discussed as it pertains to the gastrointestinal anatomy, physiology, and major disease syndromes.

Rabbits are true non-ruminant herbivores. Their digestive reservoir permits and increases the efficiency of utilization of fibrous diets. They have a large stomach and well-developed cecum relative to other non-ruminant herbivores such as the horse.

Stomach

The stomach of the rabbit holds approximately 15% of the volume of the entire gastrointestinal tract.[1] It is thin-walled, J-shaped, and lies to the left of the midline.[2] The well-developed cardiac sphincter is lined with non-glandular stratified squamous epithelium and prevents vomiting. The fundus contains parietal cells that secrete acid and intrinsic factor as well as chief cells that secrete pepsinogen. The pylorus has a well-developed, muscled sphincter.[2] The adult rabbit stomach has a pH of 1–2. The rabbit feeds frequently–up to 30 times per day of 2–8 g of food over 4-6 minute periods. The stomach normally will contain a mixture of food, hair, and fluid even after 24 hours of fasting.[2] The stomach pH of rabbits up until the time of weaning falls into the range of 5.0–6.5. Bacteria is kept in check during the first 3 weeks of life by the production of milk oil containing octanoic and decanoic fatty acids produced by the enzymatic reaction of the suckling rabbit's own digestive enzymes on the doe's milk.[2] Young rabbits acquire gut flora by consumption of the doe's cecotrophs beginning at 2 weeks of age. Milk oil production ceases at 4–6 weeks of age. By this time, some ingested organisms have colonized the cecum and hindgut fermentation can begin as the bunny weans.[2] Gastric transit time is approximately 3–6 hours.[1] The bulk in the stomach effects intestinal passage of digesta. The high voluntary feed intake (VFI) is at least 4 times higher pro rata than a 250-kg steer. It is also associated with a low gut retention time of 17.1 hours in the rabbit compared with 68.8 hours in the bovine. High VFI together with re-utilization of gut content by reingestion of

cecal material supports the rabbit's high nutrient requirement per unit of body weight and improves feed utilization for the rabbit.[3] The bovine's main volatile fatty acid (VFA) produced by rumen fermentation is propionic acid while the rabbit's main VFA is acetic acid with cecal fermentation. The primary microflora of the rabbit is *Bacteroides* species while *Lactobacillus* species is the primary microflora of the bovid.[2]

Small intestine

The small intestine is approximately 12% of the gastrointestinal volume in the rabbit.[2] The bile duct enters into the proximal duodenum. The right lobe of the pancreas is situated in the mesoduodenum of the duodenal loop. The left lobe lies between the stomach and transverse colon. There is a single pancreatic duct that opens at the junction of the transverse and ascending loops of the duodenum. The duct drains both pancreatic lobes. Technically this is the accessory pancreatic duct as the main pancreatic duct connection to the duodenum disappears during embryonic development.[1] The jejunum is the longest section of small bowel and appears convoluted. Aggregates of lymphoid tissue (Peyers patches) are present in the lamina propria with increasing prominence distally. The distal end of the ileum has a spherical thick-walled enlargement known as the sacculus rotundus. This marks the junction between the ileum, cecum, and colon. The sacculus rotundus is often called the "cecal tonsil" because of its lymphoid tissue and macrophage composition. This organ is unique to rabbits. An ileocolic valve controls movement of ingesta from the ileum into the sacculus and prevents reverse movement of ingesta back up into the ileum. The ileocolic valve opens into the ampulla coli at the junction of the ileum, colon, and cecum. There is a weak ileocecal valve that allows chyme to pass into the cecum.[2]

Gastrointestinal smooth muscle is stimulated by motilin, a polypeptide hormone that is secret4ed by enterochromaffin cells of the duodenum and jejunum. Motilin is released in response to fat while carbohydrates inhibit release. Motilin activity is not present in the cecum, but is present and stimulates smooth muscle in the colon and rectum.[1] The stomach and small intestine in the rabbit function similarly to other monogastric animals.[1] Cecotroph digestion and some fermentation takes place during the 6–8 hours they remain in the gastric fundus. Cecotrophs contain microorganisms and products of microbial fermentation including amino acids, volatile fatty acids, and vitamins. A gelatinous mucous coating protects them from some of the stomach acid. As the cecotrophs passed through the colon, lysozyme was incorporated. The lysozyme has bacteriolytic activity that degrades microbial proteins for absorption in the small intestine. Bacteria within the cecotroph produce amylase that converts glucose to carbon dioxide and lactic acid. These products along with amino acids and vitamins are absorbed primarily in the small intestest. Digestion in the stomach begins with hydrochloric acid and pepsin and continues into the proximal small intestine. Amylase from the pancreas is added, although amylase is also present from saliva and cecotrophs. The pancreas also contributes proteolytic enzymes and chymotrypsin through the accessory duct as well as most likely through small ducts connecting directly to the duodenum. Bicarbonate is secreted by the proximal duodenum to neutralize the acidity of ingesta leaving the stomach. The bicarbonate is absorbed in the jejunum. Transit time through the jejunum is 10–20 minutes and 30–60 minutes through the ileum.[1]

Hindgut

The hindgut consists of the cecum and colon. The cecum of the rabbit is large and may contain 40% of intestinal content. It has 10 times the capacity of the stomach.[2] The cecum is thin-walled and coiled in 3 gyral folds. It ends in a blind-ended tube called the vermiform appendix. This appendix contains lymphoid tissue and secretes bicarbonate that buffers the cecal acids, and water to form the cecal paste. In addition to *Bacteroides* species, there may also be ciliated protozoa, yeasts, and small numbers of *E coli* and clostridia species in the cecal flora.[2] The fermentation process in the cecum results in volatile fatty acids that are absorbed across the cecal epithelium. Cecal contents have an alkaline pH in the morning and an acid pH in the mid afternoon, termed a "transfaunation" as types of microorganisms fluctuate. In addition the predominant VFA of acetate, butyrate, and propionate are

also produced.[2] The ascending colon is divided into 4 sections.[1] The ampulla coli opens into the first section, approximately 10 cm long and having 3 longitudinal flat bands of muscular tissue (taeniae) that separate rows of haustra or sacculations.1 The mucosa of this section has small protrusions approximately 0.5 mm in diameter that are termed "warzen" or warts. This are unique to lagomorphs and greatly increase the surface are of the colon for absorption. The warts may also aid in mechanical separation of ingesta.[1] The taeniae are innervated with autonomic fibers from the myenteric plexus.[1] The second section of colon has a single taenia and fewer, smaller haustra.[1] There are segmental and haustral contractions that mechanically separates the ingesta into indigestible particles and liquid contents. As the large pellets pass down the middle of the lumen, water is re-absorbed and the are excreted as hard dry pellets. The third section is the fusus coli. It is a muscular area about 4 cm long, highly innervated, and vascular. Its mucosal surface has prominent longitudinal folds and goblet cells. It opens into the fourth section of ascending colony that is indistinguishable histologically from the transverse and descending colon.[1] The distal colon (sections distal to the fusus coli) ends at the rectum. Its mucosa has short crypts with abundant goblet cells. It is thin-walled and usually contains hard fecal pellets.[1]

Cecotrophy, not coprophagy

Cecotrophs are formed in the proximal colon and cecum. Rabbits begin consuming them between 2 and 3 weeks of age as they begin to eat solid food. Fiber material greater than 0.5 mm does not enter the cecum but transits to be formed and passed as hard fecal pellets. The smaller particles and fluid remain in the cecum or are returned to the cecum via antiperistalsis to form high nutrient particles that become coated with mucus as they pass through the colon. They are usually passed 8 hours or so after feeding, which coincides usually to nighttime. This mechanism requires high fiber diets to function properly. Low fiber diets increase cecal retention time and promote hypomotility of the entire gut, which further reduces the cecotrophs produced. Fiber in the diet should be indigestible and at least 15%.[2] A low protein diet increases a rabbit's cecotroph ingestion. A high protein diet and low in fiber reduces consumption.[2] In crude fiber terms, diets that are less than 150 g/kg of feed will almost always result in digestive upset while diets with greater than 200 g/kg crude fiber result in increased incidence of cecal impaction and mucoid enteritis. A diet devoid of fiber has a coefficient of apparent digestibility of organic matter of 0.90. This declines in a linear fashion to 0.40 when the diet contains 350 g crude fiber per kilogram of feed. Increased crude fiber of the diet increases the crude fiber of the cecal contents. This decreases the protein content. Compounded, pelleted diets require the addition of hay in order to supply a complete diet. In general, the recommendation that hay be supplied on a free-choice basis as a rule of good husbandry of the pet rabbit should be emphasized.[3]

High carbohydrate diets cause several problems. Excessive glucose allows *Clostridium spiroforme* and *E coli* to colonize.[2] Excess VFAs produced drop the cecal pH, that inhibits normal flora and allows pathogens to proliferate and colonize. Gas and toxins can be produced by pathogenic bacteria, and motility and nutrient production and absorption are interrupted. Fats such as full-fat soybeans, oilseeds can be used as a source of energy without causing cecal hyperfermentation.[2] However, feeding of vegetable fats and seeds decrease the fiber content of the diet, and lead to motility and functional depression.

It is interesting to note that rabbits have a gall bladder and secrete about 7 times the amount of bile as a dog of similar weight. They secrete mainly biliverdin rather than bilirubin. Rabbits have low levels of bilirubin reductase.[2]

Rabbits should be fed in a quiet place, preferably early in the morning and in the evening. Rabbits do not like dusty food. A rabbit will selectively take concentrates if the palatability of roughage is variable. This may result in diarrhea from consumption of too much protein relative to hay. A well-fed rabbit masticates its food extensively whereas when the rabbit is hungry, it doesn't chew to any great extent. The mastication of the fiber is necessary for dental health and normal tooth wear.

Diet recommendations

The recommended diet for a mature rabbit consists of unlimited grass hay; ¼ to ½ cup (timothy/oat if rabbit is hypercalcemic, older or obese; alfalfa only if underweight, normocalcemic) pellets per 5–6 lbs (2.5–3 kg) of body weight. Fresh foods can be 1–2 cups of chopped vegetables (preferably a mix: beet greens, broccoli, carrot and carrot tops, collard greens, mustard greens, parsley, pea pods (flat edible kind), romaine lettuce, watercress, wheat grass. Other acceptable vegetables, but less Vitamin A content: alfalfa, basil, bok choy, brussel sprouts, celery, cilantro, clover, dandelion greens and flowers (not sprayed), endive, escarole/kale, green peppers, mint, peppermint leaves, raddichio, radish tops, radish and clover sprouts, raspberry/blackberry leaves, and spinach. Table 1 lists calcium contents of some common rabbit foods. For treats and only if the rabbit is not overweight and the owner is insistent on some sort of "sweet treat," the following fruits are high in fiber and can be provided at 2 TBSP/3 kg (30 ml/3 kg) body weight daily: apple, melon, peach, plum, strawberry, blueberry, papaya, pineapple, and raspberry. Remember that rabbits evolved eating grass and herbs, not rich grains, alfalfa, and fruits. Supplementation with vitamins and other treats is not necessary. Pellets are fed as a larger portion of the diet to does in kindle starting approximately 10 days prior to delivery, as well as to growing, young rabbits up to 10 weeks of age, then the amount of pellets is scaled down to the adult amount. After weaning of the kits, the amount of pellets for the doe is decreased until a non-breeding level of appetite is established. Hypercalcemia and obesity are 2 very commonly seen diseases with dietary etiologies.

Table 1. Mean calcium and phosphorus contents (g/100 g dry matter) of feedstuffs used for pet rabbits.

Food	Calcium	Phosphorus	Dry Matter (%)
Alfalfa Hay	1.35	0.27	90
Apple	0.06	0.06	21
Barley	0.07	0.39	89
Cabbage	0.64	0.35	12
Clover (fresh) red	1.80	0.40	20
Clover (fresh) white	1.40	0.51	19
Grass	0.54	0.30	20
Corn	0.01	0.32	87
Oats	0.03	0.03	90
Peas	0.12	0.41	89
Wheat	0.07	0.39	89

Gastrointestinal illness

Rabbits that are presented with or without malocclusion but with painful abdomens, anorexia, diarrhea or lack of stool need treatment prior to correction of the oral problems. Immediate administration of analgesics and fluids often results in the rabbit beginning to eat and the gastrointestinal tract beginning to move. Table 2 can be used as a guideline for diagnosing and treating gastrointestinal disease. A detailed history and physical examination including auscultation of the abdomen may allow the practitioner to evaluate the stage of gastrointestinal distress the rabbit is in. Radiographs are useful to determine ileus. Contrast series may be utilized to determine an impaction, although barium introduced into cecums is problematic for function. The author prefers to utilize endoscopy and/or ultrasound, or an iodine-based contrast agent rather than a barium series. Most trichobezoars will move once hydration is corrected and sufficient roughage is available. Use of motility enhancers may be tried if no impaction is present. Once pain is alleviated and hydration corrected, the rabbit may begin to walk around and nibble hay, which will encourage gastrointestinal motility. While not proven, probiotics are often administered per os or intrarectally. Remember that these are usually primarily lactobacillus spp. which are not the primary microflora of the rabbit. Vitamin B complex may be given to stimulate appetite. As hepatic lipidosis may be present and playing a role in anorexia, it is advantageous to get some food into the anorexic rabbit as soon as possible. If the rabbit does not immediately start eating hay, a gavage of diluted Critical Care (Oxbow Pet Products, Murdock, NE, USA) is given. This commercial formulation can be mixed with apple juice or flavored electrolyte solution to give directly orally. Many rabbits will take hand feeding of this formula.

Rarely is surgery necessary to relieve an impaction, but if a necrotic or ischemic section of the gut is suspected, surgery may be necessary to resect the bowel. Prognosis is guarded primarily because of endotoxins produced by *Clostridium* species present in most herbivore gastrointestinal tracts. The anesthesia further decreases gastrointestinal motility, again setting up the microflora to be altered and toxins produced. It may be necessary to install an intraosseous or jugular intravenous catheter to administer antibiotics and fluids perioperatively and postoperatively for several days in these cases. Restoration of gut microbial flora and motility and postsurgery are priorities. Antibiotic choices in these cases are a balancing act as a broad spectrum antibiotic with primarily gram negative and efficacy against anaerobes should be used. Antimicrobials that primarily have a gram-positive spectrum or that do not kill anaerobes are not recommended.

Table 2. Guidelines for evaluating rabbit gastrointestinal disease.[4,5]

Parameter	Level 1 Outpatient	Level 2 Watch Closely	Level 3 Hospitalize
Appetite	Will eat greens & treats, indifferent to pellets, reluctant with hay	Refusing most greens and treat foods	Refusing everything
Activity & attitude	Normal, frisky; hiding, just not acting right	Depressed, not moving much, not grooming	Reluctant/refuses to move, dull, head down; unresponsive
Pain (abdominal) (note: teeth grinding can occur at any level)	Does not tense abdomen on palpation, but acts slightly uncomfortable. NSAID may be adequate	Tenses on abdominal palpation, shifts stance, reacts by movement or biting: moderate pain: NSAID may eliminate	"Bunny brick" – abdomen is so tense it's hard, rabbit sits with feet tucked underneath, reluctant to move. Opiate and NSAID recommended: severe pain
Stool	Normal or slightly abnormal consistency: soft-formed, very small & dry. Less quantity	Scant to none: small misshapen. May have had no stool X 24 hr	Fluid diarrhea; mucoid diarrhea; or no stool in several days. Perineum may be stained
Palpation	Normal; fluidy but non-painful; may palpate material in gut, stomach	Painful abdomen, may be hard, gassy, tensing makes it difficult to palpate	Gastric tympany; cecal tympany; mass effect; generalized painful abdomen
Cardiovascular	Mucous membranes pink, ears warm	Mucous membranes usually still pink, usually ears still warm	Pale mucous membranes; ears cool, poor peripheral blood pressure
Gut sounds	Normal or hyperactive	Decreased or none	No gut sounds
Urine	Volume & color normal; may have brown tinge	May be decreased volume, increased odor; may have brown tinge. Still alkaline	Decreased volume, increased odor, acidic, clear urine.
Body temperature	101-104°F	<101°F or >104°F	<100°F or >105 °F
Hydration	Normal or slight dehydration	Mild dehydration	Usually marked dehydration
Treatment	Diet corrections: hay, hay, and more hay! Fluids prn SC; Vitamin B inj. NSAID. Encourage exercise.	Analgesics; fluids SC and supportive care including high fiber force feeding with probiotics. Motility enhancer, antimicrobials, Vitamin B complex injection. Encourage to walk.	IV fluids to start, SC to follow. Analgesics (opiate and NSAID), antimicrobials, motility enhancer if no obstruction. Force feeding or gavage, probiotics. Supportive care (warmth, quiet).

The Guinea Pig Gastrointestinal System

Cavies are strict herbivores and are cecotrophic. Dental disease with resulting malocclusions are common and beyond the scope of this presentation. A full dental examination should be included if any gastrointestinal disorder is encountered. Cavies are monogastric with completely glandular stomachs. The lesser curvature of the stomach is small and forms an angle with the esophagus termed "the angular notch."[2] The small intestine lies in the right side of the abdomen and is approximately 125 cm in length in an adult. The small intestine is without distinguishing sections and lymphoid tissue (Peyer patches) in the lamina propria are found throughout. The large intestine begins at the ileocecal valve.

Hindgut

The cecum is the largest part of the digestive tract usually containing up to 65% of the gastrointestinal contents. It is large, thin-walled, and fills most of the left ventral abdomen.[2] It measures approximately 15–20 cm in length.[2] It has 3 white muscular longitudinal bands: the dorsal, ventral, and medial teniae coli. The saccular outpouchings between the bands are haustra. The colon appears dark green and is approximately 70 cm long. It functionally is divided into the shorter proximal section (20 cm) and the distal, longer section (50 cm). The proximal colon has mucosal folds on the mesenteric side that forms a longitudinal furrow. The furrow aids in separating high protein and smaller particles from the poorer quality material that will pass out of the colon as dry fecal pellets. Antiperistalsis transports the bacteria and higher protein particles back to the cecum for further fermentation.[2]

Physiology

Gastric emptying time is approximately 2 hours with a total gastrointestinal transit time averaging 20 hours (dry fecal pellets). Cecotrophy may be performed 150–200 times daily. Young cavies initially populate their intestinal tract by eating the sow's cecotrophs and pellets. Gut flora is primarily gram-positive bacteria with anaerobic lactobacillus. Coliforms, yeasts, and clostridia may be present in small numbers.[6] Cavies are more efficient than rabbits at digesting fiber. Satiety is determined by the distension of the gastrointestinal tract. Increasing fiber does not increase appetite.[5] A crude protein level of 18–20% is needed for growth and lactation. A crude fiber level in the diet should be 10–16%.[6]

Gastrointestinal disorders

Two conditions involving the gastrointestinal system are seen frequently, and both may be linked. The first is anorexia. The clinician needs to determine if the anorexia is primary (refusal to eat a new brand of pellets), with subsequent malocclusions, and hindgut dysbiosis (change in microflora) and motility, or if the anorexia is secondary to a hindgut disorder or dental disease. Diarrhea is the second most common condition. It needs to be determined if it subsequent to other disease or if it is a primary disease of the gut. Changes in diet, stress, illness, anesthesia, or reproduction may alter gut motility and/or gut microflora, resulting in diarrhea. Clostridial infections secondary to antibiotic therapy that did not control anaerobes is frequently the cause. Antibiotic administration has been linked to disruption of normal gut flora. A generality is that broad-spectrum antibiotics administered subcutaneously or intramuscularly are less likely to cause problems. Chloramphenicol, enrofloxacin (fluoroquinolones), and trimethoprim/sulfonamides have rarely caused dysbiosis. In some large colonies, coccidia may cause diarrhea particularly in young guinea pigs.[7] Fecal/rectal cultures, gram stains, and parasite evaluation along with history and complete physical examination including the teeth may be needed to determine the etiology. Diarrhea associated with an overgrowth of *Candida albicans* has been seen in cavies on prolonged antibiotic treatment.[7]

Treatment may involve analgesics and NSAIDS, probiotics, motility enhancers, antimicrobials, additional vitamin C, and almost always, fluid therapy. Assisted feeding with Carnivore Care (Oxbow) greatly increases the likelihood of recovery, but as cavies do not tolerate a lot of handling and injections while ill, the prognosis is always guarded!

Chinchilla Gastrointestinal System

Chinchillas share many similarities with guinea pigs, however are generally hardier and tolerate handling and treatment better than cavies. Dental disease is not uncommon, but discussion is beyond the scope of this presentation. The gastrointestinal tract is long, 11.5 feet for the small and large intestine combined in an adult.[8] The cecum is large and coiled. The colon is sacculated. The cecum of the chinchilla holds approximately 23% of the dry matter content of the large intestine compared to the rabbit (57%) and the guinea pig (44%).[8] Cecrophagy is similar to the guinea pig except that cecotrophs may be passed in the day as chinchillas feed mostly at night. Fecal excretion is primarily at night. Transit time of ingesta through the gastrointestinal tract is approximately 12–15 hours. Chinchilla nutritional needs have not been studied as extensively as the needs of rabbits and other rodents. It currently is recommended that chinchillas receive grasses and hays, and pellets containing 16–20% protein, 2–5% fat, and 15–35% bulk fiber.[8] A pellets-only diet is not sufficient for roughage and predisposes the chinchilla to enteritis. Providing 1–2 tablespoons of pellets per day, with ad lib good-quality grass hay, and 1–2 teaspoons of fresh leafy vegetables seems to be adequate for dental and gastrointestinal health for non-breeding chinchillas.

Gastroinintestinal disease

Esophageal choke has been described in chinchillas that are feed raisins, fruits, and nuts, or those consuming their bedding or post-parturient females on the placentas. Bloat or gastric tympany has been associated with overeating of clover and sudden food changes, particularly to foods rich in carbohydrates. Bloat can be alleviated with decompression of the stomach, either by passing a stomach tube or trocarization through the abdominal wall. Fluid therapy and analgesics should be administered. Gastric trichobezoars have been seen in chinchillas that are chewing their fur. Trichobezoars will usually resolve with medical treatment similar to that used in rabbits: fluids, analgesics, motility enhancers, and roughage.[9] Constipation seems to be more of a clinical problem than diarrhea. The usual cause if too much pelleted diet without sufficient roughage or fiber.[9] Fluid therapy along with small amounts of fresh foods such as apples, carrots, or leaf lettuce, along with the owner discontinuing any treat foods such as raisins, seeds, and grains usually corrects the problem. In some, a laxative or a motility enhancer may be needed until the diet is corrected. Diarrhea frequently is the result of too much fresh vegetable intake. Infectious diarrheas are accompanied by a chinchilla that presents depressed, dehydrated, and staining of the perianal area. Rectal prolapse is seen in stressed young chinchillas, and may also be a sequellae of diarrhea. The prolapse can be reduced as in other animals, but etiology should be determined. Intestinal torsion, intussusception and impaction of the cecum and/or colon have been diagnosed in chinchillas. Animals present severely depressed and with a painful and usually distended abdomen. Surgery may be required, and the prognosis is guarded.[9]

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