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### Getting acquainted with.... Bowzer's Digestive System Part 2. Small Intestine Linda Aronson, DVM

Passing through the pyloric sphincter of the stomach we enter the intestines. Partially digested food – chyme - is thrust into the intestines by peristaltic waves. The first part of the intestines is called the duodenum, because in humans it's about the as long as the breadth of 12 fingers. The total length of the small intestine of the dog is about 2.5 times the dog's length. In a 40 lb dog the duodenum is about 10" long. Most of the canine small intestine (close to 90%) is the middle jejunum, and only a very short ileum joins the small to the large intestine. (In humans, the ileum is about 40% of the length of the small intestines.) The small intestine has a huge surface area to maximize absorption of electrolytes, water and nutrients. While figures are not available for dogs, in humans the surface area is about 175 m<sup>2</sup> or the size of a doubles tennis court. This large surface is created by folds of the mucosal surface lining the intestine (triple the area of the simple tube), and small finger like projections – villi (an additional 10 fold amplification in area), and thousands of microvilli on the surface of each stomach cell (another 20-fold increase in area, for 600 times the area of a simple tube). It should be remembered that the small intestine of the primarily carnivorous dog is relatively much shorter than that of the omnivorous human.

There is a single layer of enterocytes (intestinal cells) covering the entire surface area. Interspersed there are goblet cells that secrete protective mucous. These cells live only 3-5 days, and then are sloughed off and digested. The new cells start in the "crypts" at the bottom of the folds in the intestinal wall at the base of the villi, and at this point their job is mostly to secrete intestinal fluid to keep things moving and digesting. As they mature they stop secreting and edge their way up the villus. Anything entering the body must pass through the microvilli which form a "brush border" on the surface of the enterocytes presented to the chyme, unless the intestinal lining is damaged. Many nutrient products have special transport processes to help them get across the membrane and into the enterocytes. There are also enzymes in the brush border for the final stages of protein and carbohydrate digestion. Fat-soluble molecules simply diffuse across the membrane.



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Entering the duodenum are bile and pancreatic ducts which provide enzymes to help digest nutrients to a form suitable for absorption. Pancreatic  $\alpha$ -amylase digests starch and glycogen to two-molecule sugars - disaccharides, which the brush border breaks down into glucose for absorption. Sucrose and lactose (milk sugar) are broken down by brush border enzymes too. Proteins are broken down by pepsin from the stomach, as well as trypsin and three other enzymes from the pancreas into short-chain peptides, dipeptides – (two molecule) or simple amino acids. The brush border enzymes break down the former, but dipeptides and amino acids are ready to be absorbed. The brush border enzymes also convert trypsinogen (from the pancreas) to the active trypsin, which in turn converts the other pancreatic enzymes to their active forms. Fat digestion also begins in the stomach with gastric lipase, and is continued by the pancreatic lipase. Resulting monoglycerides and free fatty acids mix with bile to form micelles for absorption. As fatty acids are absorbed the bile salts split off and can form more micelles. Ultimately bile salts are resorbed in the ileum, and recycled back to make more bile.

Most water-soluble vitamins are absorbed rapidly in the upper small intestine, some by active transport and others passively. Folic acid is produced as a metabolic by-product of normal bacteria in the upper intestines as well as being present in the diet, it is absorbed actively at low concentrations and passively when more is present. Cobalamin (Vitamin B 12) is a large molecule and requires special, selective mechanisms for its absorption. If there is ileal disease due to bacterial overgrowth dogs can develop B 12 deficiency. Fat soluble vitamins require bile salts for absorption. If fat absorption is compromised deficiencies of these vitamins, especially A & D, can be expected. Vitamin K, essential for proper clotting, is derived from the diet (K 1) and normal intestinal bacteria (K 2). The latter is mostly absorbed in the ileum and colon. Vitamin D regulates calcium absorption (as well as its retention by the kidney). Iron is absorbed in two forms, but the heme form, found in meat, is absorbed much better than the non-heme form.

The small intestine secretes and resorbs huge volumes of fluid each day, and 98% of that secreted is resorbed in the normal animal (dietary fluids replenishing the difference) so that only a little fluid is lost in the feces. Only a small reduction in reabsorption can result in diarrhea. Diet has a profound effect on fluid balance. Dogs fed on kibble excrete twice as much fluid in their feces as dogs fed meat based foods. This becomes significant only



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when a dog develops diarrhea, and this is why kibble should be avoided in dogs with diarrhea and during their recuperation.

By the time chyme arrives at the ileum most nutrients have been absorbed, but only about 50% of the fluid. Normally, the colon removes about 90% of the remaining fluid. In diarrhea originating in the small intestine, the jejunum and ileum do not resorb fluid efficiently, and the reserve capacity for colonic absorption is exceeded. In diarrhea of colonic origin not only is the resorption of fluid compromised, but inflammatory disease (as seen in inflammatory bowel disease – IBD) causes the colon to secrete fluid into the bowel, rather than sucking it out. To diagnose the cause of diarrhea it is important to determine if it originates in the large or small intestine.

The fasted intestine goes through three stages of motility. The first lasts about 20 to 30 minutes when nothing much happens, this is followed by another 30 minutes of random activity and then 5 minutes of intense contractile waves flowing from the duodenum to the ileocolic junction. This last phase serves to move digested intestinal cell “hulls,” and also to control bacterial populations within the gut. Between 10 and 20 minutes after a meal peristaltic waves pass through 5 to 15 cm sections of the intestine, moving food away from the stomach. These are interrupted by isolated contractions that stop forward motion and serve to mix the intestinal contents to improve digestion and absorption. This activity continues for about 9 to 12 hours after a meal.

The intestines normally have enormous numbers of bacteria and a variety of fungi. These usually coexist symbiotically with the dog. These bacteria arrive by mouth, and this “microflora” is usually established within a few days of birth. Some of the metabolic activity of the bacteria takes longer to develop. Distribution varies throughout the gastrointestinal tract. It is high in the mouth, drops in the stomach then gradually increases as with progression through the small intestine to such high levels in the colon that viable bacteria make up 30 to 50% of the dry weight of the feces! In the dog’s digestive tract, 84 different species of bacteria of 27 different genera, and 5 genera of fungi have been identified. Their distribution also varies along the length of the digestive tract.

Peristaltic motion of the digestive tract is the body’s primary defense against bacterial overgrowth. This is backed up by gastric acid and intestinal



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immune function, as well as antibiotic properties of bile and pancreatic fluid. In the colon especially, bacterial metabolism also plays an important role.

Given this highly complex system, it is not surprising that introducing antibiotics into the system is very disruptive. Antibiotics are selective, and some bacteria will be killed or slowed down, allowing other insensitive organisms to flourish and take over. These bacteria may hurt the lining of the intestines. This may allow the bacteria to enter the body and cause sepsis and disease. This process – translocation - is the most important cause of morbidity and death in critically ill patients. Intestinal obstruction, hemorrhagic shock, obstructive jaundice, thermal injury and endotoxemia may also cause translocation. Feeding high fiber diets and probiotics reduce the risk of translocation and diarrhea for dogs being treated with oral antibiotics.

The intestinal flora is important for normal bile and liver function, and a variety of other processes within the body. It produces fuel for the cells lining the colon. It stimulates the immune system and even activates some antibiotics. On the down side it is responsible for the production of gas. In dogs there is little contribution in terms of vitamin synthesis.

The intestines are presented with a lot of foreign substances in the form of complex molecules that have to be broken down, and the good stuff needs to be absorbed and the bad stuff kept out. In general, when presented with foreign substances the body reacts by trying to either repel them, or neutralize and digest them. The intestines have special defenses to help them. Gastric acid and proteases (enzymes that digest proteins) denature and degrade antigens, while mucus traps them and prevents them reaching the cell membranes. Tight junctions between the enterocytes also keep out unwanted invaders.

The intestines also have a very well-developed immunologic barrier provided by the GALT (gut associated lymphoid tissue). This protects the cells from invasion by pathologic organisms, and also prevents dietary building blocks, the normal flora and other antigens from setting off allergic reactions. The specific details of GALT are beyond the scope of this article, but suffice it to say that overreaction can produce as many problems as improper function. Over activity can cause the destruction of the body's own cells, hyper-reactivity and **inflammatory bowel disease (IBD)**, although this is a complex disease involving several parts of the gastrointestinal immune



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system. **Food allergy** seems to be result of defective production of immunoglobulin A (IgA) allowing antigens to enter the blood stream. Subtle defects in the immune system may prolong intestinal disease, and cause over-reactivity to certain dietary constituents.

The most common symptoms of intestinal disease are **diarrhea** and **vomiting**, but it must be remembered that these can be caused by disease elsewhere in the body. Small intestinal disease usually involves interference with the number of intestinal cells or their function. As well as loss of fluids, reduced absorption will ultimately starve the body of nutrients in the face of adequate feeding and result in loss of body mass. Some diseases result in a reduction of the brush border enzymes and carrier proteins. Inflammatory diseases can cause the enterocytes to secrete fluid rather than absorb it, lose protein, or fail to recycle the building blocks in the sloughed enterocytes. Malabsorption can occur if there is a loss of bile or pancreatic enzymes too.

Diarrhea is an increase in the fluid content of the feces together with an increase in frequency and volume.

Simple or osmotic diarrhea occurs when too much fluid is present in chyme arriving in the colon; it can also be caused by osmotic laxatives. Impaired absorption of nutrients (especially carbohydrates) is the usual cause, and fasting usually improves the situation. Malabsorption can be the result of damage to the enterocytes – acute viral enteritis or chronic enteropathy. It can also be the result of bacterial overgrowth or a lack of digestive enzymes (exocrine pancreatic insufficiency – EPI).

Exudative diarrhea occurs as a result of tissue fluids, serum, blood or mucus leaking into the intestines. Ulcers, inflammation – from parasites or bacterial infection or infiltration all produce diarrhea in this way. Severity depends on the amount of fluid lost. Secretory diarrhea is usually caused by a toxin or irritant (such as castor oil) causing the enterocytes to secrete more fluid into the intestines. Fasting rarely helps.

Motility disorders can also lead to diarrhea.

In some cases enterotoxins from bacterial infection can cause rapid waves of contractions or spasms of the intestines, but in other diseases such as corona virus or hookworm, gastric motility actually slows down. Increased motility alone does not cause diarrhea.

**Diarrhea** can have many causes. Acute, self-limiting diarrhea that usually resolves before a cause can be found, is often the result of dietary



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indiscretion, although may also be the result of parasites or exogenous toxins. Acute, severe, bloody and potentially fatal diarrhea can be caused by an infection (salmonella, parvovirus) or hemorrhagic gastric enteritis (HGE). It can also occur secondary to systemic diseases (distemper, leptospirosis) or metabolic disturbances (increased blood urea nitrogen – BUN; Addison's disease). Chronic diarrhea can result from parasites or other pathogens, partial obstruction, systemic disease – liver, kidney, Addison's; chronic large or small intestinal disease; or exocrine pancreatic insufficiency. A good history is essential in trying to narrow down this wide field to identify the cause. This should include the length and persistence of the problem, diet (including recent changes, access to garbage and other items, sensitivity to foods, etc), appetite, changes in gas production, frequency of defecation and volume, presence of vomiting (suggests inflammation somewhere and is as common with both large and small bowel problems), abdominal pain; straining to defecate – problems of the rectum and anus; changes in weight and condition; outdoor access (access to parasites, sick dogs). Excitable, inquisitive and/or aggressive dogs are more prone to stress-induced diarrhea.

The next step is examining the feces. Bulky feces indicate the small intestines or exocrine pancreas are the source of diarrhea - although a high fiber diet should first be ruled out! They are usually light in color, watery/frothy, free of mucus and usually blood (although in Beardies EPI may be characterized by bloody feces) and smell foul due to the presence of undigested food and/or bacterial overgrowth. Small volume, with a jelly-like mushy appearance is characteristic of large bowel diarrhea. Mucous without blood indicates irritable colon, while blood – either fresh and red, or black and tar like (melena) indicates infection, inflammation or neoplasia. Excess gas while typical of certain diets – especially soy based ones – indicates malabsorption – gas may be expelled or make its presence known by increased rumbling in the abdomen. Small bowel diarrhea usually increases frequency of defecation only 2 or 3 times normal, whereas increases above this, or accidents in the house are more common with large bowel disease.

Thorough abdominal palpation, evaluation of the mouth, rectum and anus may require sedation; even cooperative dogs may tense the abdominal muscles if they are experiencing pain. A complete blood count, biochemistry panel and urinalysis can rule in or out the contribution of systemic disease to the diarrhea. Fecal examination for giardia or round, hook, whip and tape worms as well as blood and fat should be performed. Electron microscopy



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can often identify viruses causing diarrhea. Salmonella and campylobacter can be isolated using special culture media. Clostridia organisms are normally present in feces, but overgrowth can be identified using assays or stained microscopic specimens. Most fungi can also be identified. X-rays can help identify megaesophagus (see part 1), aspiration pneumonia, metastatic disease, foreign bodies, partial obstruction (due to foreign bodies, intussusception – where the intestine telescopes in on itself – or tumors). Contrast films – using barium – may be required to identify some of these problems. Ultrasound helps evaluate the thickness of the intestinal wall – five distinct layers are normally visible – obstructions and content of the intestines as well as peristaltic function.

Measurement of folate and cobalamin (Vitamin B<sub>12</sub>) in the serum can localize small intestinal disease. If folate levels are low the problem is with the upper small intestine where folate is mostly absorbed, whereas if cobalamin is low, the lower small intestine is the location of the problem. The use of endoscopy and colonoscopy allow visualization and collection of biopsy specimens from much of the digestive tract, and is less invasive than surgery, however, exploratory surgery may be necessary in some cases to identify the cause of the problem and hopefully its resolution.

Diet-induced diarrhea due to indiscriminate eating, eating spoiled foods or food to which they are hypersensitive is very common in dogs. It's generally self-limiting and fasting alone is usually curative. If a dog is allergic to a particular ingredient of the diet careful detective work may be needed to identify this, and avoidance of the food in future will be necessary to avoid repeated bouts of diarrhea.

Many food allergies though are exhibited as anorexia or itchiness, rather than as diarrhea.

Diarrhea is also a common side-effect of many medications as well as other chemicals. Steroids and many of the non-steroidal antiinflammatories can cause severe and potentially life-threatening ulceration, and should be given with drugs to protect the gastrointestinal tract such as omeprazole. Similarly antibiotics should be given with probiotics to preserve the normal intestinal flora.

Parasites can cause acute or chronic diarrhea in dogs of any age, but are usually most debilitating for puppies. Reliance upon fecal exam to identify



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parasite infection may miss a lot of infections as eggs are only shed sporadically. Prophylactic treatment for worms in any animal that is failing to thrive may be prudent. However, infection is often asymptomatic. There is evidence in humans that inflammatory bowel disease (IBD) may be a response to lack of intestinal worms, and treating patients with benign pig roundworms has been very successful. However, there is a potential zoonotic risk from canine round and hookworms, especially in young children, and others handling infected animals and their feces without proper sanitary precautions. In humans, these worms can travel randomly through the body, causing blindness and even death.

**Roundworms** can live dormant in a bitch until she becomes pregnant, and then pass to the puppies through both the placenta and the milk. Heavily infected puppies have a pot belly, are painful, have diarrhea, dull haircoat, are dehydrated and have stunted growth. They may vomit up worms, or have complete obstruction of the intestines. More often however, the puppies appear perfectly normal. Adult dogs can be infected by ingesting worms in the environment.

**Hookworms** are voracious bloodsuckers, and heavy infection can result in bloody diarrhea. They can cause fatal anemia in young puppies. While bitches can pass hookworms transplacentally, they are more likely to reach puppies in the milk. Adults can ingest worms or larvae, and they can also enter through the skin. In the southeast, *Strongyloides stercoralis* is another worm that can produce hemorrhagic diarrhea, especially in young puppies. Infection occurs through the skin.

**Whipworms** inhabit the large bowel, and may cause diarrhea, but are most often asymptomatic. Dogs get them from the environment, either directly or by licking them off their paws.

**Tapeworms** are spread by fleas and lice, and the only symptom the dog usually shows is itching in the area of the anus.

Protozoal infections are caused by **coccidia** and **giardia**. Coccidia rarely cause problems even with large numbers of protozoa, except in young puppies, and then only if they are kept in areas of overcrowding and poor sanitation. In general, they have to be pretty debilitated and stressed to show diarrhea. In healthy puppies, even heavy infestations resolve without treatment. Giardia, on the other hand, has the potential for causing infection





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in animals of any age consuming contaminated food or water. It also has the potential to infect human care-givers. Diarrhea can be acute or chronic, intermittent or continuous, self-limiting or persistent. Usually it is typical of malabsorption – large volumes of foul-smelling, light colored, watery (“cow pat”) diarrhea with a high fat content. Dogs may exhibit weight loss, loss of condition, dry skin, poor hair coat, and stunted growth in young animals. Diagnosis may be difficult, and prophylactic treatment of suspected cases is advisable. Recurrence is common, and if this occurs frequently, vaccination might be a good option, although neither the AVMA (American Veterinary Medical Association) or AAHA (American Animal Hospital Association) recommend use of the vaccine.

Parvovirus, coronavirus and rotavirus can all cause **viral diarrhea** in dogs. **Parvovirus** appeared suddenly in the late 1970s, and is an acute and highly contagious disease. It has a high affinity for rapidly dividing cells, so attacks the intestines, bone marrow and lymph tissue. In the intestines it attacks the crypts and causes complete destruction of the mucosal lining with collapse and severe diarrhea. While dogs of any age can get parvovirus, it is most severe in dogs under a year of age. Puppies under 6 weeks old are protected by maternal antibodies, and the majority of older puppies and dogs are protected by vaccination (or association with dogs shedding antigen that have been vaccinated). The virus persists in the environment, after being shed in feces, for a very long time. It enters its new victims orally. Some infected dogs vomit more, others show more diarrhea. They all have a fever, dehydration and are depressed. Crowding, secondary bacterial infection, other diseases and poor sanitation worsen the prognosis, and many puppies die - usually from dehydration, endotoxic shock, electrolyte imbalance or overwhelming bacterial infection. Any puppy 6 to 20 weeks of age with acute diarrhea and/or vomiting should be treated for parvovirus while confirmation is being made. Vaccination does not rule out the possibility as it may have been given before maternal antibodies subsided. Fluids; antibiotics – if there is evidence of secondary bacterial infection; antiemetics – if there is vomiting; shock doses of corticosteroids - for endotoxemia; and withholding all food and water by mouth until 24 hours after diarrhea and vomiting has stopped are the usual treatment. Dogs are kept in isolation. Most patients will survive, although fatal complications are common.

By contrast, **coronavirus** is a much more benign disease, in which the tips of the villi rather than the crypts are destroyed. It is acute, contagious and



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diarrhea is of variable severity. Most infections are subclinical. While dogs of any age can be infected, appreciable disease is only seen in puppies between 6 and 9 weeks of age. The puppies may be depressed, but rarely have a fever. The feces vary in appearance, but often smell foul. Most animals recover quickly with fluids and anti-diarrheals. Occasionally diarrhea can persist for 3 or 4 weeks, but fatality is extremely rare and seen in newborns only. Vaccination is not recommended. **Rotavirus** may occasionally cause a self-limiting watery diarrhea in young puppies.

**Canine distemper virus** can cause severe gastroenteritis with diarrhea and fever that is hard to distinguish from parvovirus. However, there are usually other signs, discharge from the eyes and nose, pneumonia and neurological problems. Supportive treatment may reduce mortality, which is about 50%. Vaccination is effective and preventative.

Bacterial infection by *Salmonella*, *Campylobacteria*, *Yersinia*, *Shigella* and invasive strains of *Eschericia coli* invade the lining of the colon and lower small intestines producing inflammation, mucus secretion and bleeding. Bloody, mucoid diarrhea is accompanied by fever and pain. Disease may spread systemically through the blood and lymph systems. Other bacteria produce enterotoxins, which produce watery, electrolyte-rich diarrhea. In dogs, *salmonella spp* and staphylococci contaminated foods can produce this kind of diarrhea. However, while most dogs harbor potentially pathogenic bacteria, they rarely cause illness. Unless dogs are otherwise debilitated, most bacterial diarrhea is self-limiting. Treatment with antibiotics, once the causative organism has been identified, and fluid support is helpful. These organisms are potential human pathogens, however, and care must be taken by caretakers to prevent infection.

**Rickettsial Diarrhea (salmon poisoning disease)** is a highly fatal disease caused by consumption of infected raw salmon from the Pacific Northwest. Infection results in high fever, vomiting, diarrhea, anorexia, depression, discharge from the nose and eyes, dehydration and swelling of peripheral lymph nodes. Left untreated mortality is 50-90%. Treatment with tetracycline and fluid support should be begun as soon as disease is suspected.

**Canine hemorrhagic enteritis (HGE)** is a disease of unknown cause. There is a sudden onset of vomiting; profuse bloody diarrhea that is the consistency of raspberry jam and smells foul; and extreme concentration of



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the blood. It is probably the result of mucosal hypersecretion by enterocytes. One potential cause may be infiltration by *Clostridium perfringens* and or an endotoxin produced by this bacterium. It can occur in dogs of any age, but most often those between 2 and 4 years, and can recur in about 10%, while for the majority it is a single event. If untreated the circulation can collapse completely in 24 hours, but most dogs are treated promptly with fluids and balanced electrolytes causing a rapid improvement, although the diarrhea may not resolve for 24 hours. Food and water should be withheld until the diarrhea has resolved. If there is not a rapid improvement, other causes of disease – parvovirus, foreign body, intussusception or twisting of the intestines - should be sought. In Beardies and some other breeds, exocrine pancreatic insufficiency may manifest very like HGE, although hemo-concentration and prolonged capillary refill time are usually not seen.

Nonspecific acute diarrhea is treated supportively to correct fluid and electrolyte loss, resting the digestive tract by withholding oral food (and sometimes water) for 24 to 48 hours. Motility modifiers and adsorbents may be given to reduce the frequency of defecation and improve fecal consistency although there is little evidence they help the patient, they make things easier for the caretakers. Specific therapy is directed at the underlying cause of the illness, where this has been determined.

Intestinal obstruction is relatively common in dogs. It can be acute or chronic, partial or complete and can be the result of compression from outside the intestinal lumen – adhesions, hernias, strangulation, intussusception, twisting (volvulus), lesions of the wall, tumors (lymphoma, adenocarcinoma, leiomyosarcoma), inflammatory granuloma, fungal infection, stricture, abscess or hematoma; intraluminal obstruction – foreign body; functional – neurological or muscular problems, infiltration of the intestinal wall, peritonitis or low potassium (e.g. in Addison's disease); or congenital malformation. The most common problem is ingestion of a foreign body – the most common ones are toys, food wrappings, bones, sticks, corn cobs, fruit pits, stones, fabric, plant material and fish hooks and lines, but just about everything has shown up at one time or another. String, dental floss and other "linear" foreign bodies can cause pleating (plication) of the intestine on the string which can lead to multiple perforations of the bowel and peritonitis (infection of the abdominal cavity). In some cases the intestines are strangulated and lose circulation – which leads to edema and engorgement of the affected segment, loss of oxygen and cell death, which



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proceeds to bacterial overgrowth, endotoxemia, shock and death. If caught in time, the affected segment can be surgically removed. This is most common when there is twisting of the intestine, entrapment in a hernia, or **intussusception**. In dogs the latter condition most often occurs where small and large intestines meet – at the ileocolic junction. Usually this occurs in puppies under a year old. It is thought that some underlying disease (parasites, viral infection, linear string body, adhesion or tumor) disrupts normal propulsion, so that a wave of peristalsis arrives, fails to continue and causes the next segment of intestine to fold back over the previous one. One or more segments may be involved. Surgical repair is almost always necessary.

To be continued.