Gut stasis – Consequences for Fluid and Electrolyte Balance

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Overview

This lecture will draw on your prior knowledge of digestive system structure and function in different animal species, to consider the consequences of gut stasis for fluid and electrolyte balance in a range of clinical scenarios.

Peristalsis is essential for the maintenance of normal secretory and absorptive processes in the gastrointestinal tract. When motility is disrupted and stasis results, these mechanisms are disrupted with potentially severe consequences for the animal. Important differences in the volume and composition of digestive system secretions occur between species, based on the way in which they have adapted to consuming varying diets. An understanding of how digestive system processes differ between species is of vital importance in order to predict the perturbations that can result when disease states causing gut stasis occur.

What are the fluids that enter the gastrointestinal tract?

- Water (drinking or contained within food)
- Saliva
- Oesophageal secretions
- Gastric secretions
- Pancreatic secretions
- Bile
- Intestinal secretions

Saliva

[See Lecture 5 and Lecture 11 for more detail.]

Saliva is produced by glandular cells which secrete water, electrolytes, enzymes (except in fermentative digesters), and mucous. Serous cells secrete a watery, protein-rich fluid; and mucous cells produce a mucus-rich secretion. The volume and composition vary with diet and species.

Ruminant saliva is rich in sodium and bicarbonate. Bicarbonate is of particular importance as it is required to buffer the volatile fatty acids being produced by microbial fermentation of forage in the rumen, in order to maintain an optimal rumen pH of between 6 and 7. The maintenance of rumen pH is also facilitated by the rapid absorption of volatile fatty acids across the rumen epithelium into the circulation.

In contrast, horse saliva is rich in sodium and chloride, but contains much less bicarbonate, as the simple stomach in horses does not require buffering (in actuality, the glandular portion of the stomach is actively secreting hydrochloric acid).

The volumes of saliva secreted are also important to consider in different species. Because the rumen epithelium does not actively secrete fluid, the volume of fluid in the rumen is maintained via re-circulation through the salivary glands. Ruminants continuously secrete serous salivary secretions from their parotid glands, which can be dramatically upregulated in response to feeding or rumination. Diet is also an important consideration, as the more roughage that is consumed, the more saliva is produced. Hay absorbs about four times its weight in water, whereas grain absorbs approximately one time its weight in water.

Species differences in volume
- Cattle: 100-150 L/day
- Horse: 10-15 L/day
- Pig: 1-2 L/day
- Dog: 2-3 L/day

In conditions where saliva does not reach the rest of the gastrointestinal tract (usually a functional or structural obstruction of the oesophagus), the resulting electrolyte imbalances will be different between species.

Cattle lose sodium and bicarbonate, leading to the blood becoming more acidic (decreased pH; acidaemia) and the cow will also become hyponatraemic (low blood sodium) and hyperchloraemic (high blood chloride). Cattle will become quickly dehydrated due to fluid loss when saliva cannot pass into the rumen, due to the enormous volumes of saliva that are secreted.

In contrast, horses lose sodium and chloride, therefore becoming hyponatraemic and hypochloraemic, and usually the blood becomes more alkaline (increased blood pH).

The saliva of non-fermentative digesters (simple monogastric digestive systems, such as dogs and cats) has much lower concentrations of electrolytes, and volumes produced per bodyweight are smaller. Therefore, the consequences of saliva loss are not of the same magnitude.

Oesophageal secretions

Secretions from glands in the oesophagus are mainly mucous secretions, which assist the passage of food into the stomach (or rumen). They typically are small in volume and have little consequence to overall fluid balance.

Gastric secretions

[See Lecture 13 for more detail.]

Gastric secretions comprise hydrochloric acid produced by the parietal cells, digestive enzymes (pepsinogen) produced by chief cells, and mucus which is produced by mucous cells.

Secretions vary with diet. Animals that consume high protein diets (carnivores) will require larger amounts of digestive enzymes, chiefly pepsin, which involves an accompanying larger volume of hydrochloric acid secretion to occur. There is also variation in gastric mucosa between species. Many species have glandular mucosa only; however, the horse has squamous and glandular mucosa, separated at margo plicatus. There is no mucous secretion from the squamous epithelium, making this area more susceptible to ulceration when it comes in contact with gastric acid.

Ruminants have a complex forestomach system comprising the rumen, reticulum, omasum and abomasum. The rumen, reticulum and omasum have only absorptive functions, with no secretion taking place. Volatile fatty acids, water and electrolytes are absorbed in the forestomach. The abomasum is a more "typical" glandular stomach, where acid secretion occurs similarly to that of monogastric animals.

Gastric secretions amount to considerable fluid volume. Along with water that is ingested in feed and by drinking, normal function of the stomach is required for this fluid to reach the small intestine where it is absorbed. In the case of ruminants, normal rumen motility is essential for fluid to be moved through the forestomach, and for rumen fluid to adequately contact the rumen papillae for absorption.

Pancreatic secretions

[See Lecture 19 for more detail.]

Pancreatic secretion volumes vary between species. Most notably the horse has profuse and continuous pancreatic secretions which contribute considerably to the enterosystemic fluid cycle. Pancreatic fluid is rich in sodium and bicarbonate, and is alkaline. This works to buffer acidic gastric contents as they pass into the duodenum. Pancreatic fluid is secreted in three phases, as for gastric secretions.

Bile

[See Lecture 19 for more detail.]

Bile is generally high in sodium, chloride and bicarbonate at high flow rates, however presence of the gall bladder allows concentration of bile. Water and electrolytes are absorbed, and organic solutes retained. **Bile release** from the gall bladder is stimulated by chyme in the duodenum (release of cholecystokinin) and p*ositive feedback* from bile acids returning to liver via the portal circulation.

In species with no gall bladder (horses and rats), continuous secretion of bile into the duodenum occurs. Secretion volumes are relatively similar across species, proportional to their size.

Small intestinal secretions

[See Lecture 22 for more detail.]

The small intestine has functions of both secretion and absorption of fluid and electrolytes, with a net effect of fluid absorption. Functional small intestine is essential for preserving water and electrolyte balance. Generally, crypt epithelial cells have secretory roles, whereas villous epithelial cells have absorptive roles. Crypt cells basically have transporter proteins in reverse to villous cells for secretion of electrolytes. As crypt cells move upwards, they change from having a secretory role to an absorptive role.

Water absorption in the small intestine is always due to simple diffusion. Electrolytes are absorbed from the gut through various different mechanisms, which vary depending on the part of small intestine.

- Sodium: co-transport proteins, Na^+/H^+ exchanger, diffusion
- Chloride: coupled Na^+/Cl^- absorption, paracellular, $Cl^-/HCO3^-$ exchange
- Bicarbonate: much used for buffering gastric HCl, remaining reabsorbed ($Na^+/HCO3^-$ exchange)
- Potassium: simple paracellular diffusion

Secretion of electrolytes by crypt cells into the small intestine also occurs through several mechanisms. Coupled sodium and chloride secretion is the main mechanism for secretion of the electrolytes. Bicarbonate mainly enters the small intestine through pancreatic secretions; however, a large amount of bicarbonate is secreted by the ileum in the horse. This acts like saliva in the ruminant to buffer volatile fatty acid produced by the microbes of the equine caecum and colon.

Mucus is also secreted into the small intestine to protect the mucosa and assist the passage of ingesta. The Brunner's glands in the duodenum are especially productive as the mucus they produce helps protect the duodenum from the acidic chyme passing from the stomach. Mucus-producing cells are present throughout the length of the entire small intestine.

Water enters the small intestine along an osmotic gradient generated by the presence of osmotically active molecules from food (esp. salty, starchy foods) in the gut lumen. Chloride enters the gut lumen by secretion, and sodium follows to maintain electroneutrality in the gut lumen. Water then follows. Water leaves the small intestine as it follows osmotically active molecules as they are absorbed. Essentially water moves between the gut, interstitial fluid and circulation in whichever direction is necessary to keep the ingesta iso-osmotic.

Water and solutes move between the gut and blood by transcellular or paracellular absorption into the lateral spaces (extracellular fluid between enterocytes and capillaries), and then into the vascular system. Nutrients enter the capillaries by diffusion from the lateral spaces, and water follows.

Fluid shifts between gut and circulation are therefore intimately related and are of a large magnitude. Water enters capillaries through osmotic force from solutes, and also due to hydrostatic pressure that builds up in the lateral spaces. The capillary endothelium is the path of least resistance, so usually water tends to enter blood rather than go back into gut lumen.

The intestines have a large capacity for fluid, and therefore act as a major fluid reservoir for the circulation. Peristalsis is essential for the unidirectional flow of fluid through the GI tract, therefore anything that causes peristalsis to be disrupted has major consequences for fluid and electrolyte balance in the animal. Obstruction of the gastrointestinal tract can be structural (e.g. foreign body, mass), or functional where motility is disrupted without a physical blockage (termed ileus, which is often caused by inflammation).

When the intestine is obstructed, absorption ceases and water is secreted into the gut lumen. This sequesters fluid, Na^+, K^+, Cl^- in the small intestine, making them unavailable to the circulation. Because of the large magnitude of fluid shifts between the gastrointestinal tract and the circulation, consequences of gut stasis can be severe.

Large intestine

Large intestinal anatomy is variable between species, most notably being very large in horses where it is a site of fermentation. Both absorption and secretion take place in the large intestine, with a net effect of fluid absorption. In dogs, there is mainly absorption of water and electrolytes. In horses, water and electrolytes, as well as volatile fatty acids are absorbed.

In the horse, mixing and segmentation bring volatile fatty acids into contact with the mucosa for absorption. Reverse peristalsis or retropulsive peristalsis ensure there is enough time for microbial action on the ingesta. Secretions of bicarbonate, sodium and chloride are added to the colonic contents. As mentioned above, bicarbonate is also produced in large quantities in the ileum of the horse, which buffers volatile fatty acids. Water follows electrolytes into the colon; however, absorption of water and electrolytes is also occurring simultaneously. Therefore, there are large fluxes of fluid between the colon lumen and circulation. The horse typically absorbs 100-150 L of fluid from the large colon per day. The small colon of the horse functions mainly for absorbing any remaining water, but also has some secretory actions.

When the colon is inflamed, the damaged colonic mucosa cannot function normally. Absorption and secretion are disrupted, with sequestration of water and electrolytes in the colon, resulting in diarrhoea, which can be potentially very watery and of a large volume. Loss of water and electrolytes in diarrhoea can lead to low electrolyte values in the blood, and dehydration/hypovolaemia. These changes often cause the blood to become more acidic (acidaemia).

Assessment of the gastrointestinal tract

The gastrointestinal tract of veterinary patients can be examined through several different ways. Some of these are common to all species, while some will be specific to certain species, or can only be used in large or small animals.

Examination of the mouth

The oral cavity should be examined for any evidence of dental disease, mucosal lesions, or any other abnormalities of the structures contained within the mouth. In large animals such as horses and cattle, extra light is usually needed to assess the caudal aspect of the oral cavity.

Auscultation

Auscultation of the gastrointestinal tract can be done by placing a stethoscope over the abdomen. Gastrointestinal sounds, known as borborygmi, should be heard if motility is normal. In ruminants, rumen contractions can he heard by placing the stethoscope over the left paralumbar fossa. One to three rumen contractions should be heard every minute. The ileocaecal valve flushing sound in horses is important, usually occurring every 30 to 90 seconds. Borborygmi can also be ausculted in the abdomen of dogs and cats.

Palpation

Palpation of the abdomen will vary depending on the size of the animal. For small animals such as dogs and cats, palpation can be performed externally. This can also be achieved in neonates of larger species, such as calves and foals. For adult large animals, abdominal palpation can be performed through the rectum. The size of some smaller ponies and cattle may prohibit palpation per rectum. In small ruminants and camelids, abdominal palpation is usually restricted to external ballottement of the abdomen

Imaging

Radiography and ultrasound are the most common imaging modes for assessing the gastrointestinal tract. In large animals such as horses and cattle, radiography of the abdomen must usually be performed in a referral facility as portable x-ray units used in the field are not powerful enough to penetrate the abdomen. Radiography and ultrasound are both commonly used to assess the gastrointestinal tract in small animals. Other imaging modalities for the gastrointestinal tract in small animals include magnetic resonance imagining (MRI) and computed tomography (CT). Endoscopy can be used in many species to assess the pharynx, oesophagus, stomach, and proximal small intestine of most species (it is usually only useful in ruminants up to the oesophagus due to the large amount of feed contained within the rumen). In small animals (dogs and cats) the rectum and colon may also be assessed using endoscopy.

Peritoneal fluid analysis

A sample of peritoneal fluid can be obtained and analysed in order to give an indication of the health of the gastrointestinal tract. Mild-moderately high white blood cell counts and protein levels in peritoneal fluid indicate inflammation of the gastrointestinal tract, whereas moderate-severely increased white blood cell counts and protein levels indicate ischaemia of a part of the gastrointestinal tract.

Passage of an orogastric/nasogastric tube

Passing a tube into the stomach or rumen is especially useful in large animal species. In horses it allows the veterinarian to determine whether there is an accumulation of fluid in the stomach, as horses cannot vomit due to the anatomy of their stomach. If accumulated fluid is not removed from a horse's stomach, there is risk of gastric rupture. In ruminants, obtaining a sample of rumen fluid allows assessment of pH and rumen microbe health.

Cardiovascular parameters

As fluid shifts between the gastrointestinal tract and circulation are large and the two systems are intimately related, cardiovascular parameters such as heart rate, pulse quality, temperature of the extremities and mucous membrane colour and capillary refill time should also be assessed when gastrointestinal disease is present.