Visualization of Equine Gastrointestinal Anatomy

J. N. Moore

College of Veterinary Medicine, University of Georgia, Athens, GA, USA.

Many veterinary students and new equine practitioners have difficulty understanding the anatomy of the horse's gastrointestinal tract, and developing a working understanding of the intestinal displacements that can occur. In many cases, this is because many of us are visual learners who have difficulty developing mental 3-dimensional images from written descriptions and 2-dimensional drawings in textbooks. In an effort to address some of these difficulties, we have created a series of 3-dimensional computer-generated images of the horse's gastrointestinal tract under normal and abnormal situations. These images are used to reinforce basic concepts taught in gross anatomy classes, and to depict how some of the common intestinal displacements might occur. We also have strived to create visual representations of the structures that might be palpated during a rectal examination of horse with specific gastrointestinal abnormalities.

Creating a Transparent Digital Horse

We viewed as our first task the creation of a realistic digital horse, complete with 3-dimensional representations of what we considered to be the important anatomical structures within the abdominal cavity. We used high end computer hardware and software to create these 3-dimensional structures, to portray them from different vantage points, and to create animations depicting some of the more difficult to understand intestinal displacements.

We used a combination of approaches to create the abdominal organs, making a special effort to remain as anatomically accurate as possible. These approaches included creating miniature clay models of various portions of the gastrointestinal tract, referring to descriptions and illustrations in a variety of anatomy texts, photographing the abdominal organs of horses in the pathology department, and calling on the expertise of other faculty members in the College of Veterinary Medicine. We also used artistic license to develop some of the images and animations, primarily as a result of minor differences in details among the textbooks.

While our overall aims were to make the various portions of the gastrointestinal tract realistic and, therefore, understandable, we quickly recognized the need to include other structures as landmarks. These included the relevant portions of the horse’s axial skeleton, ribs, diaphragm, vena cava, aorta, kidneys, pancreas, liver, and cranial mesenteric artery. Although some of these structures ended up being deleted from some of the animations, we thought it was necessary to have them all present initially to help orient the novice regarding the relative positions of the individual portions of the gastrointestinal tract.

When we built the digital representations of the equine gastrointestinal tract, we did it organ by organ, starting with the largest portions of the gastrointestinal tract, the large colon and cecum. As we added the other structures, we paid strict attention to maintaining the relative sizes of the individual organs, and minor adjustments in size or shape were made as each was positioned within the shell of the horse’s body. As a result, we were able to create and position all of the relevant portions of the gastrointestinal tract, and allow them to be viewed from different vantage points.

Once we had created the models on our development computers, we chose to deliver our animations as QuickTime Movies, because the QuickTime program is free to the public and is cross-platform (available for many computers, e.g. Windows, Macintosh, etc.) Using QuickTime, it was possible to isolate individual portions and provide different views of each. A feature of QuickTime, Virtual Reality (VR), allowed us to create complex interactive images that gave the viewer full control over the view he/she wished to use to examine the gastrointestinal tract either as a unit or as individual pieces. These VR movies allow the viewer to rotate the image through 360 degrees at his/her own rate and preference.
These VR movies became more important after representations of some of the intestinal displacement had been completed. They can be rotated to view relevant portions of the displacement, and examine the position of the intestinal tract from either side of the horse, the ventral abdomen (to simulate the position of the intestine during colic surgery), and from the rectal view. Due to the critical importance of the rectal examination during the evaluation of horses with colic, we also paid strict attention to the rectal view of the gastrointestinal tract under normal and abnormal situations. In an effort to mimic what might be felt during the rectal examination, we created a special rectal exam view in which structures cranial to the level of the cranial mesenteric artery, and thus out of the veterinarian’s reach, are obscured.

**Anatomic Principles**

The stomach, which normally has a capacity of 8 - 16 liters, is located on the left side of the horse’s abdomen beneath the rib cage. The stomach has three basic functions, namely storage, mixing, and breakdown of feed. Although fluid leaves the stomach quickly, feed particles are retained for more than 48 hours while digestion is initiated by hydrochloric acid and periodic contractions of the muscles in the stomach wall. The peculiar anatomic arrangement between the distal esophagus and the cardia permits the movement of gas and fluid into the stomach but not out, thereby creating a functional one-way valve. Consequently, abnormalities which interfere with the normal aboral movement of fluid through the small intestine may cause the accumulation of this fluid in the stomach ("gastric reflux"), severe dilation and, if untreated, gastric rupture.

The small intestine is comprised of the duodenum, jejunum and ileum. The initial descending portion of the duodenum is positioned dorsally on the horse’s right side, where it is suspended from the dorsal body wall by a short (3 - 5 cm) mesentry. Pancreatic enzymes and bile are added to the ingesta in the proximal portion of the duodenum. The short mesentry precludes the duodenum from being involved in small intestinal displacements that involve twisting of the intestine on its mesentery ("volvulus"). In the right paralumbar fossa region, the duodenum turns towards the horse’s midline and passes across the dorsal aspect of the base of the cecum. It is at this point in the abdomen that the duodenum can be felt on rectal examination if the duodenum is distended with gas or fluid, as occurs in horses with proximal enteritis.

As it crosses the dorsal midline, the duodenum changes course as the ascending duodenum. The mesentery then lengthens at the origin of the jejunum, and it is this characteristic long mesentery that permits loops of the jejunum to rest on the dorsal surface of cecum and large colon on the ventral portion of the abdomen. The jejunum is approximately 20 m long and its length, coupled with its long mesentery, allow it to be involved in small intestinal volvulus and incarcerations. At the termination of the jejunum, the wall of the intestine becomes muscular, the lumen narrows and an antimesenteric mesentery originates. The terminal 45 cm of the small intestine, the ileum, joins the cecum at its dorsal medial aspect, with the junction being identified by the attachment of the antimesenteric ileal mesentery to the dorsal cecal band. This ileocecal fold ligament is used as a landmark to locate the ileum at surgery.

The cecum is a large, blind-ended fermentation vat, which is situated primarily on the horse’s right side, extending from the paralumbar fossa region to the xiphoid cartilage on ventral midline. The cecum is 1.5 - 2 m in length and holds approximately 30 liters of feed and fluid. Contraction of the cecal musculature results in a coordinated mixing of the ingesta with the microorganisms that digest cellulose.

After the digestive processes in the cecum have altered the consistency and makeup of the ingesta, it passes through the cecocolic opening into the first portion of the large colon, the right ventral colon. The right ventral colon is situated on the ventral aspect of the abdomen from the flank region to the rib cage. This portion of the colon has a diameter of approximately 25 - 30 cm and is divided by haustra into sacculations, which help mix and retain plant fibers until they are more fully digested. As the result of aboral muscular contractions, the ingesta moves towards the horse’s left side through the sternal flexure of the ventral colon, and then into the left ventral colon. Inside the left ventral colon, which also is large and sacculated, the ingesta passes caudally towards the horse's left flank area. Near the pelvic region, the diameter of the colon decreases markedly and the colon folds back on itself. This region, which is called the pelvic flexure, is the initial portion of the unsacculated left dorsal colon.

Presumably due to the abrupt decrease in diameter, the junction between the left ventral colon and pelvic flexure is the most common location for impactions. Results of intestinal motility studies involving this region of the horse’s colon provide additional information regarding the development of pelvic flexure impactions. Normograde peristaltic contractions in the left ventral colon move ingesta aborally towards the left dorsal colon, and similar contractions in the wall of the left dorsal colon move the ingesta towards the diaphragmatic flexure. In contrast, retrograde contractions of the muscles of the left ventral colon move the ingesta in a retrograde fashion, from the pelvic flexure region towards the sternal flexure. It has been
hypothesized that a pacemaker region in the pelvic flexure senses either the size or the consistency of the feed particles in the ingesta, and then initiates the appropriate motility pattern. If digestion has proceeded sufficiently, the ingesta is moved in a normograde direction. If, however, additional digestion is necessary, the muscular activity occurs in a retrograde direction to retain the ingestion in the ventral colon. This hypothesis has been proposed to account for the common clinical occurrence of obstruction at or near the junction of the left ventral colon and the pelvic flexure.

The ingesta then moves towards the horse’s right side through the diaphragmatic flexure and into the right dorsal colon; the diameters of these portions of the colon are large, with that of the right dorsal colon reaching 30 - 35 cm. There are no sacculations in these portions of the dorsal colon, and the right dorsal colon is closely attached to the right ventral colon by a short fibrous mesentery and to the dorsal body wall by a tough common mesenteric attachment with the base of the cecum. In contrast neither the left ventral nor the left dorsal colons are attached directly to the body wall, allowing these portions of the colon to become displaced or twisted.

Ingesta in the right dorsal colon then moves into the short transverse colon, which has a diameter of approximately 10 cm and is situated cranial to the cranial mesenteric artery. The transverse colon is fixed firmly to the dorsal-most aspect of the abdominal cavity by a strong short fibrous mesentery. Finally, the ingesta enters the sacculated descending colon, which is 4 - 5 m in length and has a diameter of approximately 10 cm.

**Selected Intestinal Abnormalities**

**Left Dorsal Displacement of the Large Colon** -
Left dorsal displacement of the colon occurs when either the pelvic flexure or the entire left colon moves over the renosplenic ligament. Because the renosplenic ligament does not attach to the dorsalmost aspect of the spleen, a natural cleft exists between the spleen and left kidney. It has been hypothesized that the colon distends with gas, the spleen contracts as part of the response to abdominal pain, the colon then moves dorsally over the renosplenic ligament, and then the spleen refills "trapping" the colon. We used this hypothesized route to develop the animation, concentrating on dorsolateral movement of the colon, and medial displacement of the spleen as the weight of the colon is borne by the renosplenic ligament. There are several findings on rectal examination indicative of a left dorsal displacement. These include palpating the pelvic flexure over the ligament, palpating the bands of the left ventral colon running dorsocranially towards the left kidney, or detecting that the spleen is displaced towards the middle of the abdomen.

**Pelvic Flexure Impaction** -
While one of the most common sites of impaction is the pelvic flexure region of the left colon, the impacted ingesta usually is not restricted to the pelvic flexure itself. In fact, it is not uncommon for the entire left ventral colon to become obstructed with dry, impacted ingesta. Because the common name of the condition would suggest the more restricted location of the impacted ingesta, we thought it would be prudent to develop an animation that depicts initiation of the impaction at the pelvic flexure, with subsequent expansion to involve the majority of the left ventral colon. Because the diagnosis is made on rectal examination, we focused on producing a realistic visual representation of what can be palpated. The impacted mass may be felt extending cranially in the abdomen and the affected segment of bowel identified by palpating the longitudinal bands on the surface of the ventral colon.

**Right Dorsal Displacement** -
In this common colonic displacement the left colons move laterally around the base of the cecum to lie between the cecum and the right body wall. There are at least two possible routes by which this displacement can develop. In one hypothesized route, the pelvic flexure moves cranially around the cecal base, caudally to the pelvic region, and then medially and cranially to lie near the diaphragm. In the process of developing this displacement, the colons twist on their longitudinal axis near the base of the cecum. In the other route, the colon becomes distended with gas, and the cranialmost aspects of the ventral and dorsal colons move caudoventrally and then rotate on their long axis. This results in the pelvic flexure resting near the diaphragm. Regardless of the path the colon actually takes, the rectal examination findings are the same, with the taenia of the colon running transversely across the pelvic inlet and difficulty encountered when attempting to palpate the ventral cecal band. Although there may be some interference with venous drainage from the affected colon, usually the arterial supply remains intact and so the prognosis associated with this disease is quite good. While the animation depicting the movement of the colon around the cecum seems to help students understand how this displacement occurs, more informative views are available on the QuickTime VR movie. This allows the viewer to rotate the image of the final displaced colon, thereby providing a view of the condition from any point of view.
Large Colon Torsion/Volvulus -
Large colon volvulus is the most life-threatening displacement affecting the horse’s large colon. Although the term "torsion" has been used for years to indicate that the colon has twisted upon itself, the involvement of the mesentery between the ventral and dorsal colons dictates that the condition should be called a "volvulus". Because the twist occurs at the level of the cecocolic ligament and, therefore, out of reach on rectal examination, veterinary students commonly have difficulty envisioning how this condition develops and what might be palpated on rectal examination. For these reasons, we produced animations that view the condition from the cranial aspect of the abdomen where the twisting of the colons is readily apparent, as well as from the rectal view to depict what might be palpated during a rectal examination. If the volvulus is less than 270 degrees, the bowel may be obstructed but not ischemic. If the volvulus is 360 degrees or greater, strangulation obstruction of the entire left colons occurs. As was mentioned previously for the right displacement, the QuickTime VR movie allows the viewer to rotate the image to view of the volvulus from the surgical point of view.

Small Intestinal Strangulation Obstruction -
While some veterinary students may have opportunities to perform rectal examinations on horses with some of the more common or less serious causes of colic, less frequently do they get the chance to palpate horses with distended small intestine. Consequently, they tend to have difficulty envisioning how the affected small intestine is positioned in the caudal aspect of the abdomen and how incarcerations through mesenteric rents or the epiploic foramen might occur. Although we contemplated creating an animation of an epiploic foramen entrapment, we decided that the more rational approach would be to develop a more straight-forward incarceration of distal jejunum-proximal ileum through a mesenteric rent. The resulting animation depicts movement of the intestine through the rent, thickening of the intestinal wall due to impairment of venous drainage, obstruction of the intestinal lumen and blood supply, and distention of the jejunum proximal to the obstruction.

Conclusion
Based on the responses we have received from veterinary students, there appears to be a place for 2- and 3-dimensional images/animations in teaching basic topographical anatomy, explaining how certain intestinal displacements might develop, and providing the learner with more control over the rate at which he/she reviews information that may be difficult for some people to envision. It is important to recognize that computer-generated images and animations, whether they are created in 2- or 3-dimensions, can not replace true life experiences. While these images augment the students’ time spent studying and manipulating the horse’s gastrointestinal tract in the anatomy laboratory or on the post-mortem floor, they do not replace these hands-on experiences nor the time and effort required to become proficient performing a thorough rectal examination.

Note - Portions of this material were excerpted from the 2001 AAEP Proceedings.

All rights reserved. This document is available on-line at www.ivis.org. Document No. P0702.1203.